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A SILVER–PITCHBLENDE DEPOSIT AT CONTACT LAKE, GREAT BEAR LAKE AREA, CANADA.[1]

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ABSTRACT.

The B.E.A.R. silver-pitchblende deposit at Contact Lake, Great Bear Lake area, lies in granodiorite, 500 feet from granite. There are three types of veins: Type I, dark gray quartz veins; Type II, finely banded, white, comb-quartz veins, mineralogically and texturally similar to the large quartz veins of the Great Bear Lake area; Type III, carbonate veins with cobalt, nickel and silver minerals.

Six stages of mineral deposition are recognized in the formation of the Main Vein, as follows: (1) tabular bodies of altered granodiorite; (2) magnetite-hematite veins; (3) veins of Type I, gray quartz veins; (4) aplite dikes; (5) veins of Type II, white, finely banded, comb-quartz veins; (6) veins of Type III, carbonate veins with cobalt, nickel, bismuth, silver, and uranium minerals. Periods of marked deformation separate stages (3), (4), (5), and (6). The wall rock alteration and mineralogy of each stage are described.

The first three stages are classed as pneumotectic to hypothermal; stage (5) mesothermal; and stage (6) mesothermal to epithermal. Native silver was deposited above a temperature of 200° C., contains minute amounts of mercury, and is largely hypogene. The lead-uranium ratio in the pitchblende indicates an age of 650 million years or Keweenawan.

Evidence is presented to show that the silver and pitchblende of this deposit are either co-magmatic with the late quartz diabase dikes and sills of probable Keweenawan age, the youngest exposed intrusives of the region, or are related to some younger, unexposed intrusive.

Evidence from a large number of occurrences in the metallogenic province in which the B.E.A.R. deposit occurs, indicates

[1] A portion of a thesis submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy at the Massachusetts Institute of Technology, May, 1935.

that the silver and pitchblende of these deposits, likewise, were deposited subsequent to minor deformation which followed the intrusion of the late quartz diabase dikes and sills.

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INTRODUCTION.

THE silver-pitchblende deposit on the north shore of Contact Lake, Northwest Territories, Canada, was discovered in August, 1931, and is operated by the Bear Exploration and Radium Company, Ltd. The deposit lies nine miles southeast of the Eldorado silver-pitchblende mine at Labine Point, Great Bear Lake (Fig. 1).

Acknowledgment is made to the officials of Bear Exploration and Radium Limited for permission to publish data secured from the property in 1933. Mr. R. Treloar kindly supplied specimens from the first level, developed in 1934. Appreciation and thanks are due to Professor Newhouse, and Professor Buerger, under whom this work was carried out, and to other members of the Department of Geology of the Massachusetts Institute of Technology, for advice and assistance. Thanks are expressed to Professor E. L. Bruce of Queen's University for critically reading the manuscript.

GENERAL GEOLOGY OF THE GREAT BEAR LAKE AREA.

The general geology of the Great Bear Lake area has been described by D. F. Kidd,[2] H. S. Robinson,[3] C. Riley,[4] and others. It has been summarized by the writer in a paper in which the detailed geology of the area north of Contact Lake is described, and in which evidence is presented to show that certain revisions of previously prepared tables of formations for the Great Bear Lake area were necessary.[5] The revised table of formations based thereon is presented on page 742. The geology of the Echo Bay district is shown in Fig. 1.

GEOLOGY OF THE AREA NORTH OF CONTACT LAKE.

Part of the area north of Contact Lake (Fig. 2) is underlaid by rocks of the Echo Bay Group[5] comprising porphyritic volcanics (mainly andesite), feldspar porphyries and meta-argillite. One outlier of the Cameron Bay Group occurs immediately south of East Bay. The rocks of both groups strike generally north-northwest and dip moderately northeast.

A large mass of granodiorite intrudes and metamorphoses the above rocks, replacing many of their original minerals by chlorite, actinolite, epidote, magnetite and pyrite. The exposure of this mass is elongated northwest-southeast and both the northeast and southwest contacts dip northeast.

Small tabular bodies of dark green to black altered granodiorite strike northeastward, across the granodiorite mass. In these bodies the original minerals of the granodiorite have altered and are replaced partially by chlorite, actinolite, epidote, magnetite

[2] Kidd, D. F.: Great Bear Lake-Coppermine River Area, Mackenzie District, N.W.T. Can. Geol. Surv., Summ. Rept. (1931), Pt. C: 47–71; Great Bear Lake Area, N.W.T. Can. Geol. Surv., Summ. Rept. (1932), Pt. C: 1; Rae to Great Bear Lake, Mackenzie District, N.W.T. Bur. Econ. Geol., Can. Mem. 187, 1936.

[3] Robinson, H. S.: Notes on the Echo Bay District, Great Bear Lake, N.W.T. Can. Inst. of Min. and Met., Bull. 258: 609–628, 1933.

[4] Riley, C. S.: Some mineral relationships in the Great Bear Lake Area. Can. Min. Jour., 54: 146–147, 1935; The Granite-Porphyries of Great Bear Lake. Jour. of Geol. 43: 497–523, 1935.

[5] Furnival, G. M.: Geology of the area north of Contact Lake, N.W.T. Canada. Amer. Jour. Sci. 237: 476–499, 1939.

TABLE I.

TABLE OF FORMATIONS.

Quaternary		Silt, clay, gravel, and morainal material
		---------- Unconformity ----------
Precambrian (?)		Large quartz veins (banded quartz).
Precambrian	Keweenawan	Basic Sills and Dikes (quartz diabase, quartz-enstatite diabase)
		---------- Intrusive Contact ----------
		Little disturbed sandstone, quartzite, and conglomerate (Hornby Bay Series).
		---------- Unconformity ----------
	Pre-Keweenawan	Large quartz veins (massive quartz).
		---------- Major faulting ----------
		Biotite Granite (Dowdell Point and related masses); Lindsley Bay granite-porphyry.
		---------- Intrusive Contact ----------
		Basic Dikes (red feldspar-bearing).
		Granodiorite; Tabular bodies of altered granodiorite; Gneissic grey granite (Benoit Lake mass) and possible other acid plutonic masses.
		---------- Intrusive Contact ----------
		Sedimentary and Volcanic Complex:
		(*a*) Cameron Bay Group-conglomerate, tuff, argillite, etc.
		---------- Unconformity ----------
		(*b*) Echo Bay Group-porphyritic volcanics, tuff, argillite, quartzite, conglomerate, etc.

and pyrite. The alteration was caused by solutions, acting along fractures developed in the granodiorite during the closing stages or shortly after its consolidation, which are believed to be genetically related to the granodiorite.[5]

A mass of pink to light coloured coarse grained biotite granite, with medium grained gray phases outcrops along the north shore of Contact Lake. It intrudes all the rocks mentioned above. It is composite in character, consisting of sills that strike east-west and dip 35° north. Aplite dikes are minor intrusives of the granite. Quartz-enstatite diabase dikes intrude the granite and the older rocks. These are members of the widespread group of quartz diabase and quartz norite sills and dikes of probable Keweenawan age.

FIG. 1. Geology of Echo Bay district, based largely on map prepared by D. F. Kidd, 1932 but altered to include data of H. S. Robinson and the author. The area north of Contact Lake (Fig. 2), and the Thompson Group of claims is outlined. (Courtesy, American Journal of Science.)

Following the intrusion of the pink biotite granite the rocks were subjected to two periods of deformation, in both of which the direction of shortening is northeast-southwest.

VEINS.

A large number of veins of different characteristics, present in the rocks north of Contact Lake, can be grouped on the basis of mineralogy, texture, and age relations under three types as follows:

Type I.—Ten veins consist of massive fine grained, dark gray quartz with pyrite, chalcopyrite, hematite, magnetite and arsenopyrite in small amounts. These are found only in the granodiorite and many lie along the tabular bodies of altered granodiorite. They vary in strike from N 40° E to N 60° E.

Type II.—Forty-five veins consist of massive and finely banded white comb quartz with varying amounts of siderite, ankerite, calcite, hematite, pyrite, chalcopyrite, bornite and chalcocite. The wall rocks are generally chloritized sericitized, silicified and to a less degree carbonated and pyritized. Veins of this type are present in the rocks of the Echo Bay and Cameron Bay Groups, the granodiorite and the biotite granite. They range in width up to one hundred and fifty feet. Three of these lie along fractures occupied by veins of Type I.

Veins of Type II traverse and alter the tabular bodies of altered granodiorite and associated gray quartz veins of Type I. They resemble texturally and mineralogically the large quartz veins of the district.[6]

Type III.—Ten veins consist of siderite, ankerite, rhodochrosite, dolomite, calcite, barite, clear glassy quartz, chlorite, and a wide range of metallic minerals including cobalt-nickel minerals. Silver is present in five of these and pitchblende in one. The wall rocks are chloritized and carbonated for short distances.

These veins in all cases lie along or near fractures occupied by earlier formed veins. Vein matter characteristic of Type II is present along eight of the veins, and vein matter characteristic of

[6] Furnival, G. M.: Large quartz veins of Great Bear Lake, N.W.T. Canada. ECON. GEOL., 30: 843–859, 1935.

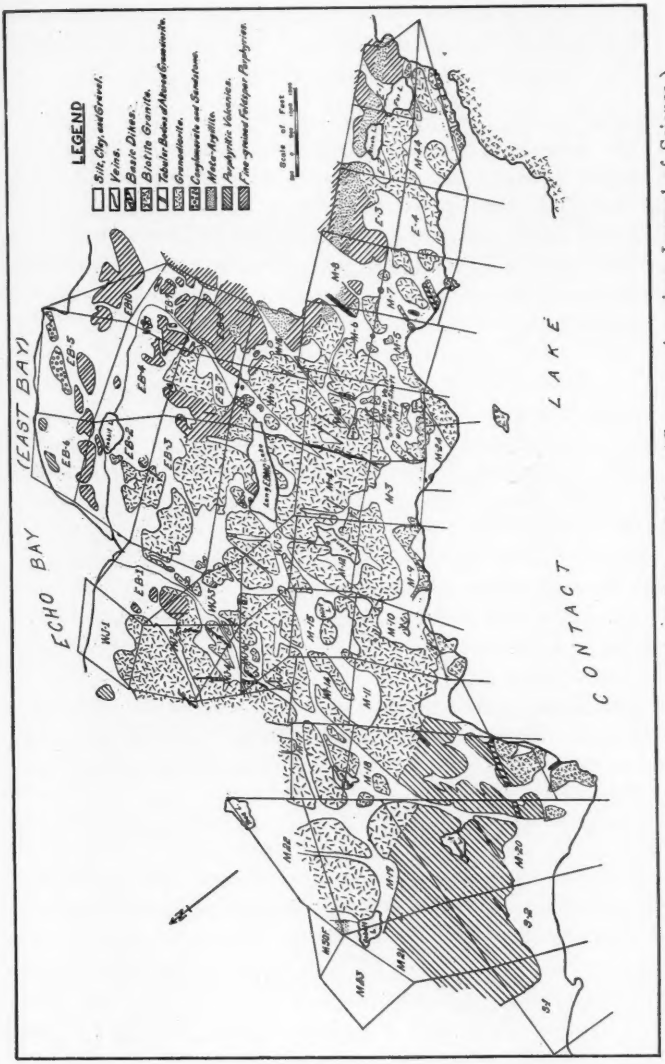


FIG. 2. Detailed geology of area north of Contact Lake. (Courtesy, American Journal of Science.)

both Type I and Type II is present along two of the veins. Where evidence is available the carbonate veins are later than veins of Types I and II.

THE MAIN ZONE.

The main silver and pitchblende bearing zone lies astride the boundary between claims M–1 and M–2, in granodiorite, five hundred feet north of its contact with the pink biotite granite. The vein system is exposed for a length of 400 feet and has been drilled for 1200 feet. In 1933 an adit was driven 480 feet on the ore zone, 80 feet below the surface. Later, the first level was established 125 feet below the adit.

General Structure.

The vein system is complex. It consists of a large number of small anastomosing and branching veins that lie along warped surfaces of fracture. The main vein consists of lenses up to five feet wide. Branch veins up to one foot wide diverge across a width of forty feet at the northeast. The vein system has an average strike of N 75° E and a steep dip to the southeast, but sharp reversals of both are common.

The complexity of the ore zone is the result of a sequence of periods of mineral deposition, with intervening periods of structural readjustments along the original fracture. "Horses" of altered country rock and vein breccias are abundant in the wider portions of the main vein. Between lenses where the vein narrows to less than a foot wide shearing, slickensided surfaces, and fault gouge are present.

Vein History.

The history of mineral deposition in the main zone can be considered in six distinct stages arranged in chronological order commencing with the oldest, as follows:

Stage I. Tabular bodies of altered granodiorite.
Stage II. Magnetite-hematite veins.
Stage III. Veins of Type I, dark gray fine grained quartz veins.
Stage IV. Aplite (micropegmatite) dikes.

Stage V. Veins of Type II, white finely banded comb quartz veins.

Stage VI. Veins of Type III, carbonate veins.

Stage I.—The main vein lies along and has replaced in large part one of the tabular bodies of altered granodiorite. Dark green altered granodiorite is present as discontinuous sections along either wall of the main vein, as fragments in the vein, and where the vein narrows between lenses of later vein material. The minerals of the granodiorite are replaced by chlorite, garnet, epidote, actinolite, pyrite, magnetite, hematite and arsenopyrite. Minor amounts of rutile and muscovite are present. Garnet is present as rounded grains, seamed by chlorite and carbonate, actinolite as veinlets and aggregates of radiating fibres with platy hematite, and epidote as grains, veinlets and irregular masses. The original texture of the granodiorite is preserved in places. Four hundred feet northeast of the deposit one of the tabular bodies of altered granodiorite outcrops.

Stage II.—Pale green to red veins, up to three inches wide, occur at places along the main vein and in altered wall rock near the veins, and like the occurrences of the tabular body of altered granodiorite are a notable feature of the main vein where it narrows between lenses of later vein material.

The veins consist mainly of intimately mixed, finely crystalline magnetite and hematite, in a gangue of chalcedonic quartz, finely divided chlorite and siderite. Epidote, actinolite and platy hematite are present as irregular aggregates and seams. Other minerals present are rutile, rounded grains of red garnet, muscovite, biotite partially altered to chlorite, and scattered grains of pyrite, chalcopyrite and arsenopyrite.

The magnetite-hematite veins cut across remnants of the tabular body of altered granodiorite. The close occurrence along the ore zone of the veins with the tabular body of altered granodiorite and the similarity of their mineralogy suggest that the solutions from which the minerals of these veins were deposited, though later, are related in origin to the solutions that resulted in the formation of the tabular body of altered granodiorite.

Stage III.—Dark gray fine-grained quartz occurs with remnants of the tabular body of altered granodiorite. The gray quartz is present as irregular masses, stringers and lenses up to one foot wide, along the main vein in a manner suggesting a once continuous vein. Pyrite and chalcopyrite are abundant, and, with scattered crystals of arsenopyrite, replace the gray quartz and the wall rocks. At places the chalcopyrite forms massive irregular lenses up to ten inches wide.

The gray quartz replaces and encloses remnants of the tabular body of altered granodiorite. Definite evidence of the age relation of the gray quartz veins to the magnetite-hematite veins was not found. However, along the main vein they are closely associated with remnants of the tabular body of altered granodiorite and it is believed they are closely related in time and source. This inference is supported by the close association of similar veins to other tabular bodies of altered granodiorite elsewhere in the granodiorite mass.

Stage IV.—Two aplite dikes up to one and a half inches in width occur irregularly along the main vein. They are composed of microperthite, quartz and a micrographic intergrowth of quartz and feldspar.

These dikes cut through the highly altered and chloritized granodiorite and are cut by the white banded quartz and the late carbonate veins. They are mineralogically similar to the aplite dikes, which are younger than and are considered to be minor intrusives of the pink biotite granite.

Stage V.—The lenticular habit of the main vein was assumed at the time of deposition of the white, finely banded, comb quartz veins. Commonly a single vein up to one foot in width is present, but in the wider portions of the lenses two and three veins occur across a width of five feet. Between lenses, the banded quartz narrows to one or two inches in width. Branch stringers and vein breccias with fragments up to several feet across are common.

The fine banding, which is due to a zonal distribution of liquid and solid inclusions in the quartz, is most prominent along the margins of the veins and around the walls of included fragments

Towards the middle of the veins the quartz is coarse, comb structure is prominent, and vugs and druses are common. Siderite is present in small quantities. The metallic minerals, hematite, pyrite, chalcopyrite, bornite and chalcocite occur widespread as scattered grains and irregular masses.

The fragments cemented by the banded quartz consist of relatively unaltered and partially altered granodiorite, remnants of the tabular body of altered granodiorite, and massive fine grained gray quartz. The minerals of these fragments have been replaced to a varying extent by chalcedonic quartz and finely divided hematite.

That the alteration of the granodiorite to the tabular body of altered granodiorite is in no way related to the white banded quartz, but was formed prior to a period of fracturing and brecciation that preceded the introduction of the solutions resulting in the formation of the white banded quartz veins, is indicated by two facts. First, among the fragments cemented by the banded quartz are some that contain the actual contact between unaltered granodiorite and the tabular body of altered granodiorite. Second, branch veins of the white banded quartz pass through remnants of the tabular body of altered granodiorite into unaltered granodiorite.

Veins of the white banded quartz traverse and displace the magnetite-hematite veins, the fine grained gray quartz veins, and the small aplite dikes.

Stage VI.—Veins of siderite, ankerite, rhodochrosite, dolomite and a large number of metallic minerals including the various cobalt, nickel, silver minerals and pitchblende.

The carbonates fill numerous transverse fractures across the main vein, enclose fragments derived from the earlier-formed vein material described under the preceding stages, and fill vugs and druses in the white banded quartz veins. They vary from dark purplish red to brown, pink, gray and white, and from finely to coarsely crystalline. Many of the veins are composed of finely banded vari-coloured carbonates in colloform arrangements, generally siderite, ankerite, and dolomite, with interbanded films of

hematite-bearing chalcedonic quartz around vugs and druses. The latter are commonly filled with coarsely crystalline rhodochrosite, calcite and scattered euhedral crystals of glassy quartz. In contrast to the intimately mixed carbonates, siderite and rhodochrosite each occur separately in massive stringers up to four inches wide. Stringers of siderite are transected and replaced by rhodochrosite and calcite. The siderite is clouded with tiny inclusions, whereas the rhodochrosite and calcite are relatively free of inclusions. Siderite is generally the most coarsely crystalline, rhodochrosite tends to be finer, dolomite very fine, and calcite variable in texture. Chlorite occurs as finely divided aggregates in seams and veinlets and as phantom spherulitic structures. Finely divided hematite is abundant, and is probably the cause of the dark purple colour of some of the carbonates.

The carbonate veins include fragments of, and vein, cross-cut and fault, the tabular body of altered granodiorite, the magnetite-hematite veins, the fine grained gray quartz veins, the aplite dikes and the banded white quartz veins. The carbonate veins, like the banded white quartz veins, also pass through the tabular body of altered granodiorite into slightly altered, then relatively fresh granodiorite.

The evidence indicates that the carbonate veins and their associated minerals have been deposited along the vein system following a period of brecciation subsequent to the formation of the banded white quartz veins. No evidence of deformation later than the carbonate vein stage, other than minor jointing, was found.

Mineralogy.

Physical and optical characteristics, etch reactions and microchemical tests were used for mineral determination. In order to facilitate the comparison and determination of physical characteristics, a diamond point hardness tester similar to and standardized with that designed by Talmage, and a two-tube single comparison eye piece, colour comparator were used.[7]

[7] These instruments were constructed by the Department of Geology, Massachusetts Institute of Technology, similar to those designed by S. B. Talmage, ECON. GEOL. 20: 168 and 531, 1925.

Iron Minerals.

Hematite.—Hematite is abundant, widespread and was deposited with every period of mineralization throughout the formation of the deposit. Platy hematite is an important constituent of the remnants of the tabular body of altered granodiorite, where it occurs with actinolite. Hematite occurs finely divided and as platy crystals in the early magnetite-hematite stringers intimately mixed with magnetite.

Hematite is present in the white finely banded comb quartz veins, as rosettes, irregular masses and veinlets, filling vugs, and coating the tips of quartz crystals. It occurs with bornite, chalcopyrite and chalcocite, and is interstitial to the comb quartz, with chalcedonic quartz and chlorite.

Several generations of hematite may be recognized in the late carbonate veins. It occurs in one or more bands interbanded with carbonates of various compositions filling vugs. Small spherules of finely divided hematite in the carbonate have centers composed of finely crystalline carbonate. Many of these are surrounded by thin films of chlorite and are replaced by native silver. Fragments of early vein matter and of country rock are surrounded by films of fine-grained chlorite and hematite.

Much hematite occurs with pitchblende, both as irregular masses surrounding pitchblende spherules and as minute crystals in the pitchblende. Tiny seams in gangue, which in thin-section show radioactive halos, in oblique illumination are found to contain fine hematite. It is present in small amounts with all the metallic minerals of the late carbonate veins. It veins native bismuth.

Hematite is heavily disseminated in the wall rock adjacent to pitchblende shoots.

Magnetite.—Small grains and crystals of magnetite are widely disseminated in the tabular body of altered granodiorite and in altered and chloritized wall rock. Some magnetite is secondary after hornblende. Magnetite replaces hematite in the magnetite-hematite veins. Some magnetite is present as scattered crystals and grains and as veins in red garnet. Magnetite is an early

mineral in the deposit and is related largely to the tabular body of altered granodiorite and to the magnetite-hematite veins.

Pyrite.—Pyrite is widespread as an early mineral but is present only in small amounts in the banded comb quartz veins and the late carbonate veins. It occurs in remnants of the tabular body of altered granodiorite and in chloritized altered wall rock, as disseminated cubes and pyritohedrons that are micro-brecciated and in part replaced by bornite, chalcopyrite, and chalcocite, resulting in a " bursted bomb " structure. Irregular masses of pyrite replace the massive gray quartz. Pyrite veins magnetite and hematite in the magnetite-hematite stringers.

Arsenopyrite.—Arsenopyrite is widespread in small amounts. It veins the magnetite and hematite in the magnetite-hematite veins, and occurs as scattered crystals and grains with pyrite and chalcopyrite. Where associated with pyrite it was found that the pyrite is micro-brecciated whereas the arsenopyrite is not, suggesting a later age for the latter. It occurs in chloritized altered granodiorite as grains and crystals with famatinite and aikenite (?).

In the late carbonate veins arsenopyrite is interbanded with cobaltite as rims surrounding rosettes of safflorite-loellingite (Fig. 10); it also encloses safflorite-loellingite in dendrites.

Copper Minerals.

Bornite, Chalcopyrite, and Chalcocite.—Bornite, chalcopyrite, and chalcocite are widespread and abundant. One generation of these minerals is apparently related to the banded white quartz veins and a second to the late carbonate veins. Some chalcopyrite appears to be related to the massive fine-grained gray quartz.

These minerals occur together as irregular masses, veinlets and disseminated grains in the remnants of the tabular body of altered granodiorite, in the chloritized and silicified granodiorite, and in the magnetite-hematite veins where they vein and replace magnetite, hematite, arsenopyrite and micro-brecciated pyrite. Large masses of chalcopyrite up to one and a half feet wide replace the massive fine grained gray quartz.

Irregular masses of bornite, chalcopyrite, and chalcocite, replace the quartz of the white finely banded comb quartz veins. In places, chalcocite occurs massive in veinlets one inch wide. Chalcocite and hematite commonly occur together, and hematite forms "emulsion" intergrowths in chalcocite. Chalcopyrite forms replacement intergrowths in bornite. The chalcocite in general has sinuous contacts with the bornite and at places forms pseudo-eutectic intergrowths with it. However, in several places, veinlets of chalcocite occur in the bornite. In one section bornite was found clearly veining chalcocite; this bornite may belong to the later generation.

Bornite, chalcopyrite, and chalcocite fill fractures in, and replace the late carbonate veins. Here, they show age relations similar to those in the banded quartz veins, and, although overlapping, they occur in the order of bornite, chalcopyrite, and chalcocite. Tetrahedrite, pearcite, and native silver with these minerals fill radial cracks in pitchblende spherules. Although bornite is veined by pearcite, it forms intergrowths with pearcite and tetrahedrite. Chalcopyrite forms pseudo-eutectic intergrowths with tetrahedrite and bornite. Chalcopyrite and chalcocite vein tetrahedrite. Chalcocite occurs in places as small concentric structures and spherules with carbonate centers. These may be secondary after hematite.

Megascopically, the copper sulphides show a dendritic habit in the late carbonate stringers. Under the microscope the dendritic structure is seen to be inherited from the cobalt nickel arsenides through partial replacement. More complete replacement has left only remnants in the sulphides and the dendritic structure is not conspicuous.

Chalcopyrite and bornite with hematite, pearcite, calcite, rhodochrosite and euhedral crystals of glassy quartz fill vugs in the late carbonate veins.

Chalcocite from the banded white comb quartz veins and the late carbonate veins is isometric.

Tetrahedrite.—Tetrahedrite is widespread in small amounts as veinlets and irregular masses in the late carbonate veins generally with bornite, chalcopyrite, and chalcocite. With these minerals it

fills radial cracks in pitchblende spherules. It forms vermicular intergrowths with bornite, which it also veins, and pseudo-eutectic intergrowths with bornite and with chalcopyrite.

Algodonite (Cu_6AS).—Algodonite was recognized in only one specimen from the late carbonate veins. It occurs as irregular masses with galena, and tiny veinlets of it lie along cleavage planes of the galena. It veins chalcopyrite, remnants of which are present in it, corrodes crystals of arsenopyrite, and occurs with native silver replacing the central zones of dendrites of cobalt-nickel arsenides.

Chalcostibite ($Cu_2As \cdot Sb_2S_3$).—Chalcostibite was found in only one section. It occurs in a quartz carbonate gangue with native bismuth, which it veins, and with chalcopyrite with which it has mutual relations.

Famatinite.—Famatinite is present in small amount as veins and irregular masses with arsenopyrite, bismuthinite and aikenite (?) in chloritized and silicified granodiorite. It is present as grains in aikenite (?).

Pitchblende.

An analysis, made of a specimen of pitchblende from this deposit, is given in Table II.[8]

TABLE II.

ANALYSIS OF THE PITCHBLENDE.

Insoluble residue	2.17		
(of which SiO_2)		(1.95)	
Impure soluble silica	0.76		Difference perhaps TiO_2
(Pure soluble silica)		(0.55)	
PbO	2.63		
(Pb)		(2.44)	
ThO_2	Traces		
Rare earths	1.98		
Fe_2O_3	5.65		
Al_2O_3	1.21		
U_3O_8	31.02		
(U)		(26.31)	
H_2O (−110°)	0.21		
H_2O (110°–300°)	0.35		
CuO	0.67		
Loss on ignition (300–1000°)	19.53		

Analyst: F. Hecht, Vienna.

[8] Professor A. C. Lane, National Research Council, Washington, D. C., kindly forwarded a specimen of pitchblende from the B.E.A.R. deposit to F. Hecht, Vienna, for analysis.

The pitchblende occurs as anastomosing seams up to one-quarter inch wide and in the form of dendrites, spherules, and ring-like structures in the late carbonate veins. The gangue is

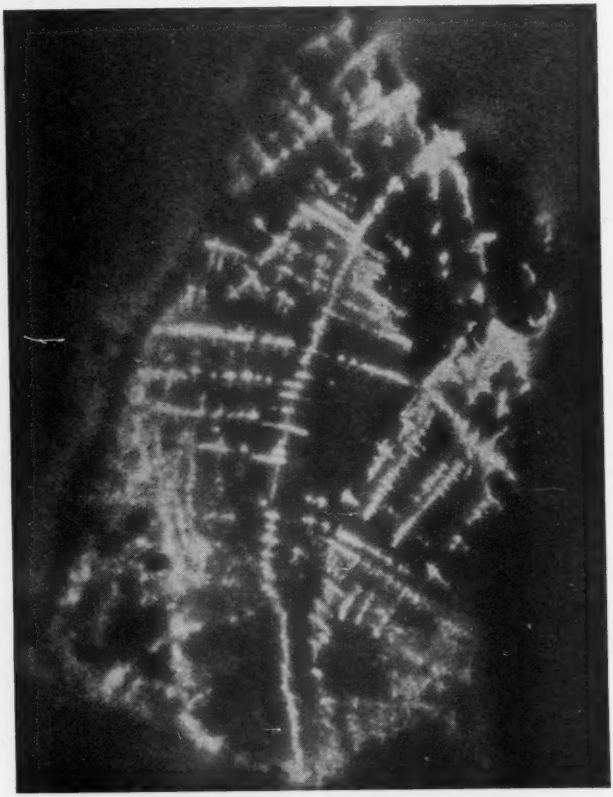
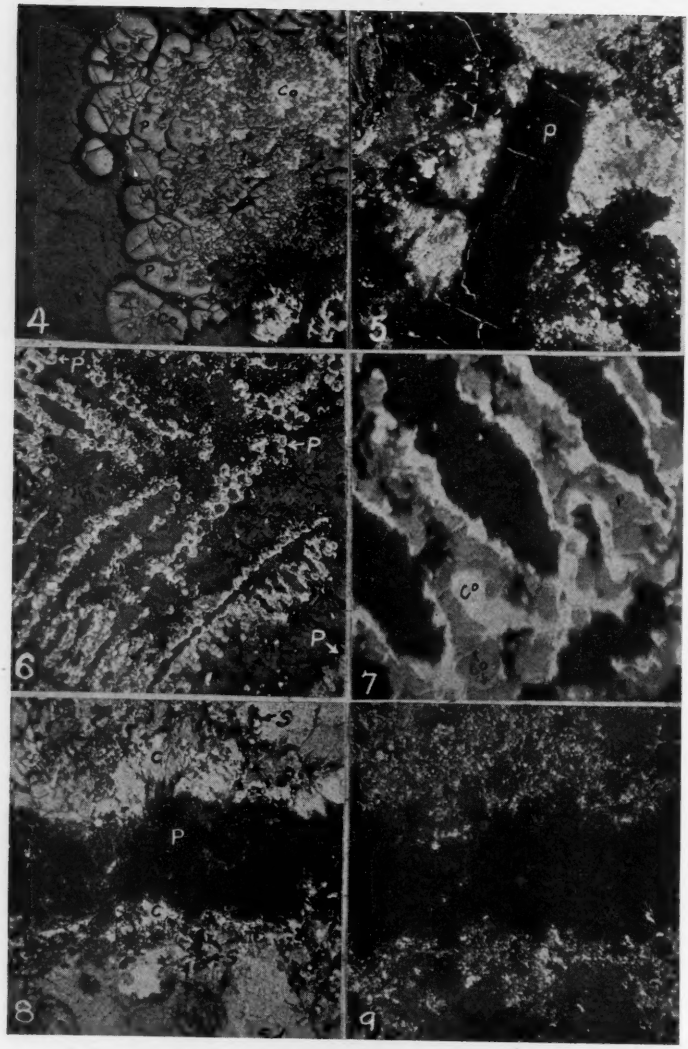


FIG. 3. Radiograph of dendritic pitchblende from the adit level (×2.5, exposure 25 hours).

composed mainly of siderite with minor amounts of calcite and rhodochrosite and small remnants of both the gray quartz and the white banded quartz.



FIGS. 4–9

Individual spherules (Fig. 4) vary in diameter up to 1 mm. across and have numerous radial cracks that are filled by cobalt-nickel minerals, bornite, chalcopyrite, chalcocite, tetrahedrite, pearcite, native silver, native bismuth, hematite, bismuthinite, carbonates and quartz. The cores of many of the spherules are replaced by the later minerals and at places only a shell of pitchblende remains.

A dendritic habit is common (Figs. 6, 7). The centres of many of the dendrites are occupied by minerals other than pitchblende. The dendrites consist of a series of skeletal crystals of pitchblende, rings of pitchblende or both; some have central zones the full length of the dendrites, which are occupied by carbonate and quartz. In places, individual grains or crystals of these minerals occupy the interior of the skeletal crystals and rings of pitchblende, and in many cases it is fine grained carbonate. The radiograph of dendritic pitchblende in siderite (Fig. 3) shows clearly the pattern of the dendritic structure to be cubic rather than rhombic.

Many of the small irregular and anastomosing seams of pitchblende in the carbonate veins and adjacent altered wall rock are of microscopic dimensions and could only be recognized in thin sections by the presence of radioactive halos. These halos extend as much as 2 mms. from the pitchblende.

Seams of pitchblende extend into the wall rocks of the shoots and pitchblende has replaced andesine and orthoclase (Fig. 5).

FIG. 4. Pitchblende (P) spherules with radial cracks filled with cobalt arsenides and native silver (Co). Dark gray, carbonate. × 55.

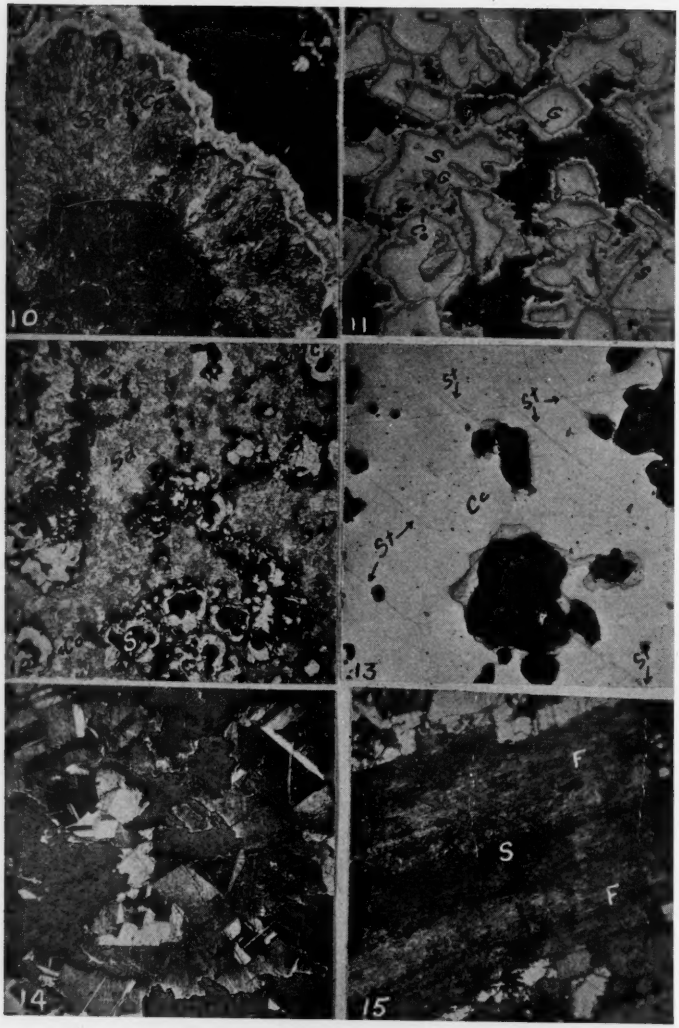
FIG. 5. Pitchblende (P) almost completely replacing a crystal of plagioclase feldspar in altered wall rock. Thin section, × 25.

FIG. 6. Dendrites of pitchblende (P) and cobalt arsenides, mainly cobaltite (Co) in a siderite and quartz gangue. × 85.

FIG. 7. Enlarged view of portion of Fig. 6. Cobalt arsenides (Co) veining pitchblende (P). Dark gray to black is gangue. Oil, × 370.

FIG. 8. An individual frond of dendritic pitchblende (P) bordered by calcite (C) in a siderite gangue (Sd). Native silver (S) is concentrated at the contact of calcite and siderite. The dark fringe immediately adjacent to the pitchblende is a radioactive halo. Thin section, × 25.

FIG. 9. Part of Fig. 8 by Silverman oblique illuminator; pitchblende, black; native silver, white; gangue, dark gray. Thin section, × 25.



FIGS. 10–15

Hematite and native silver occur in large quantity with the pitchblende in the wall rocks.

Specimens of dendritic pitchblende in siderite exhibit the following sequence: (1) pitchblende dendrite; (2) a zone of calcite practically free of native silver, which surrounds the dendrite; (3) a zone of abundant native silver in siderite immediately adjacent to (2). The silver of this zone diminishes outward into the siderite. These relations are clearly shown in Figs. 8 and 9. Evidently the silver and pitchblende were deposited at about the same time and no doubt from the same solution.

Cobalt-Nickel Minerals.

The cobalt-nickel minerals identified are cobaltite, safflorite-loellingite, glaucodot, niccolite, gersdorffite, rammelsbergite, and breithauptite. These occur mainly in the late carbonate veins, although small amounts are present in earlier vein matter and country rock near carbonate veins. Skeletal crystals, rosettes, dendritic and other colloform structures are common to them (Fig. 12).

Rosettes are commonly composed of cores of safflorite-loellingite bordered by films of arsenopyrite and cobaltite (Fig. 10). The safflorite-loellingite is present as interlocking mosaics of irregular grains. The rims of cobaltite and arsenopyrite fit around

FIG. 10. Rosette of etched safflorite-loellingite (Sa), bordered by films of cobaltite (Co, unetched) and arsenopyrite (As, slightly etched). × 50.

FIG. 11. Polish etched specimen of skeletal crystals of cobaltite (Co), the centres of which are filled with native silver (S). Small grains of glaucodot (G), are present in the cobaltite. × 50.

FIG. 12. Cobalt arsenides (Co) in colloform structures in a siderite (Sd) gangue. The interiors of the colloform structures are filled with calcite (C) and native silver (S). Thin section, × 30.

FIG. 13. Parallel blades of unmixed stromeyerite (St) in chalcocite (Cc). × 40.

FIG. 14. Native silver from the first level, lightly etched and showing a homogeneous coarse recrystallization texture; dark is carbonate gangue. × 55.

FIG. 15. Crystal of plagioclase (F) in altered country rock partially replaced by native silver (S). Thin section, × 30.

grains and at places extend inward along grain boundaries suggesting the minerals composing the rims formed subsequent to the cores. In one specimen rammelsbergite forms the cores of rosettes and is rimmed by safflorite-loellingite.

The dendrites are commonly composed of more than one mineral; films of cobaltite and arsenopyrite enclose dendrites of safflorite-loellingite. Although thin sections show that the dendrites follow cleavages, crystal boundaries, and grain boundaries of the carbonates, their pattern is cubic rather than rhombic (Fig. 6).

Cobaltite (Fig. 11), gersdorffite, and rammelsbergite occur as skeletal crystals, the centers of which are filled largely by native silver and niccolite.

Cobaltite and safflorite-loellingite are widespread and abundant. Niccolite is abundant on the first level but does not occur at the adit level or on surface. Breithauptite is widespread in small amounts and occurs as small grains in colloform masses of cobaltite, rammelsbergite and niccolite. Gersdorffite and glaucodot were recognized only in specimens from the first level. The former occurs as small grains and scattered crystals in cobaltite and niccolite. Glaucodot is present as scattered grains in skeletal crystals of cobaltite.

Cobaltite and safflorite-loellingite, with other minerals fill radial cracks and replace the centers of pitchblende spherules. Cobaltite veins pitchblende dendrites (Fig. 7).

Sphalerite.

Sphalerite is rare and occurs as scattered grains with arsenopyrite and famatinite in chloritized and silicified granodiorite and in the late carbonate veins. Sphalerite includes tiny lenses of chalcopyrite.

Galena.

Galena, though rare, is more abundant than sphalerite. It occurs with algodonite and chalcopyrite in the late carbonate veins. Thompson reports that in one section, tiny veinlets of galena and chalcocite are present in sphalerite.[9]

[9] Thompson, Ellis: The mineralogy of the silver-uraninite deposits of Great Bear Lake, N.W.T. Univ. of Toronto Studies, No. 36, p. 27, 1934.

Bismuth Minerals.

Native Bismuth.—Native bismuth occurs widespread as disseminated crystals up to a quarter of an inch long in stringers of calcite and quartz. Euhedral crystals of quartz are enclosed by the bismuth. Native bismuth veins cobaltite and lies along radial cracks in pitchblende spherules which it replaces.

Bismuthinite.—Small quantities of bismuthinite are present with aikenite (?), famatinite, and arsenopyrite in chloritized and silicified granodiorite, and with native bismuth and small amounts of chalcopyrite in calcite-quartz stringers of the late carbonate stage. Bismuthinite replaces the cores of and fills radial cracks in pitchblende spherules.

Aikenite (?) ($Cu_2S \cdot 2PbS \cdot Bi_2S_3$).—A mineral that was tentatively identified as aikenite forms irregular masses and veins in chloritized and silicified fragments of country rocks, with arsenopyrite, sphalerite and famatinite. It veins arsenopyrite and is present as scattered blebs in famatinite.

Silver Minerals.

Pearcite.—Pearcite is widespread as grains and irregular masses in the late carbonate veins and occurs as selvages along many of them, particularly those of rhodochrosite. It occurs with calcite, rhodochrosite and quartz filling vugs in the late carbonate veins. With bornite, chalcocite, chalcopyrite, tetrahedrite and native silver it fills radial cracks in pitchblende spherules. Pearcite veins bornite and chalcocite. In one specimen it was found with copper sulphides in a quartz gangue.

Stromeyerite.—Stromeyerite is widespread. It invariably occurs with chalcocite and native silver. It forms parallel blades (Fig. 13), and isolated masses in chalcocite, and in one specimen was found as a narrow zone bordering chalcoeite in contact with native silver.

The universal occurrence of stromeyerite along parallel cleavage planes in chalcocite suggests that it has formed by unmixing from a solid solution. Schwartz has shown that stromeyerite may form by unmixing from a solid solution of chalcocite and argen-

tite.[10] The excess of chalcocite over stromeyerite indicates the solid solution was rich in chalcocite relative to argentite. This may account for the absence of argentite in the deposit. Blades of stromeyerite when etched show a bladed structure due to inversion of orthorhombic stromeyerite to isometric stromeyerite at a temperature near 93° C.[11]

Stromeyerite at the contacts of native silver and chalcocite probably formed at the time of deposition of the later native silver.

Native Silver.—Native silver is widespread and abundant. It is present in all types of veins but is most abundant in the late carbonate veins. It is present as dendrites, irregular masses, disseminated grains, and leaves.

Native silver is more abundant in remnants of the tabular body of altered granodiorite and in chloritized, altered granodiorite than in fresh wall rock. It selectively replaces the feldspars of the wall rocks (Fig. 15), and occurs with hematite, chlorite, calcite, and pitchblende. Silver is present in leaves, mainly in highly chloritized wall rock, along the margins of included fragments of altered country rock and of gouge seams. It is disseminated as grains and small seams in the dark-gray, fine-grained quartz lenses, and in the magnetite-hematite veins, the minerals of which it veins and replaces.

The quartz and the copper sulphides of the banded white quartz veins are veined and replaced by small quantities of native silver.

Dendritic silver is the common form of native silver in the late carbonate veins, and occurs only in these veins. It is particularly well developed where other metallic minerals are absent. Silver occurs as disseminated grains and irregular masses, commonly replacing the carbonates along cleavage planes and around crystal and grain boundaries. More silver occurs with calcite and rhodochrosite than other carbonates, and local concentrations of silver occur with aggregates of chlorite in the veins. Native silver veins and replaces pitchblende, the cobalt-nickel minerals, tetrahedrite, pearcite, stromeyerite, arsenopyrite, native bismuth,

[10] Schwartz, G. M.: Relations of chalcocite-stromeyerite-argentite. Econ. Geol., 30: 132, 1935.

[11] Schwartz, G. M.: *Op. cit.* p. 138.

galena, bornite, chalcocite and chalcopyrite, but shows a decided preference for bornite as a host. It forms subgraphic intergrowths with chalcocite and " emulsion " intergrowths in bornite. It fills the centres of skeletal crystals of the cobalt-nickel minerals, replaces the cores of colloform masses of these minerals, and occurs as spherules that are secondary after hematite and chlorite.

The native silver was found to contain a small amount of mercury but no antimony. Specimens etched lightly with dilute HNO_3, after careful polishing with a soft cloth show a homogeneous, coarse, re-crystallization structure (Fig. 14), which Carpenter [12] has shown is found only in silver deposited above its recrystallization temperature of 200° C.

Unknown Minerals.

Four unknown minerals were found but because they occur only in very minute quantities, incomplete data were obtained. These will be referred to as Minerals *A, B, C,* and *D.*

Mineral *A* occurs in small quantities with native bismuth in the late carbonate veins.

Mineral *B* is present with cobaltite and native silver in the late carbonate veins. (This may be a cobalt-nickel mineral.)

Mineral *C* occurs as small masses and veinlets with native bismuth, chalcostibite, chalcopyrite and native silver in the late carbonate veins. Mineral *C* veins chalcostibite and encloses small masses of chalcopyrite.

Mineral *D* occurs with native silver, veining the cobalt-nickel minerals in the late carbonate veins.

Mineral Distribution.

Silver and pitchblende are present for seventy-five feet along the main zone on surface; silver occurs in smaller quantities beyond this in the main zone and in branch veins. At the adit level, contrary to Kidd's statement,[13] pitchblende occurs in four shoots,

[12] Carpenter, H. C. H.: A metallographic investigation of native silver. Trans. Inst. of Min. and Met. (London). 41: 382–402, 1932.

[13] Kidd, D. F.: Rae to Great Bear Lake, Mackenzie District, N.W.T. Bur. Econ. Geol., Canada, Mem. 187: 39, 1936.

each from twenty-five to thirty-two feet long, and as much as two and a half inches wide. Pitchblende has been intersected in diamond drill holes between the adit level and surface. Four shoots of silver occur along the adit level. These vary from 30 to 74 feet long and from 1.25 to 4.9 feet wide. Average silver content of the shoots ranges from 72 to 261 ozs. per ton. The pitchblende shoots coincide with the silver shoots.

The concentrations of silver and pitchblende occur in the lenses along the fracture zone; where the zone is narrow there is no pitchblende and little silver. The greatest concentrations of silver on the adit level occur immediately above horizons at which the lenses pinch sharply, and where the zone dips at comparatively low angles or changes sharply in strike or dip. Fractures are apt to be more open at points of greater irregularity in strike and dip than elsewhere.

The history of the development of the fracture zone has been complex, movements have occurred at various times and in various directions and amounts. Therefore, the distribution of the "open spaces" or lenses along the zone will be entirely erratic, and generalizations regarding the position of undiscovered ore shoots, or even of the extension of known ore shoots cannot be made safely.

Niccolite, which occurs only rarely on surface and at the adit level, is present in large quantities on the first level. Other nickel-bearing minerals such as gersdorffite and breithauptite, which are rare on surface and at the adit level, are widespread on the first level. It appears that maximum deposition of nickel occurred at lower levels, whereas deposition of cobalt was greater at the adit level and on surface.

The copper sulphides do not show any noteworthy changes in distribution. Sufficient specimens of other minerals, recognized in polished sections, have not been examined to permit conclusions regarding their distribution.

Wall Rock Alteration.

The wall rock alterations accompanying the different types of veins are generally superimposed along the main vein. However,

branch stringers of the various types diverge from the main vein and at places pass into comparatively fresh granodiorite, thus making possible a study of the wall rock alteration accompanying each type of vein.

Alteration Along the Tabular Body of Altered Granodiorite.

Chloritization is predominant near remnants of the tabular body of altered granodiorite. The granodiorite is darkened for a distance of three feet from the altered body. Chlorite selectively replaces andesine, hornblende and biotite in the outer two feet. Some carbonate, sericite and magnetite occur with the chlorite. More intense alteration in the first foot is marked by the presence of epidote, actinolite and hematite in increasing quantities with the chlorite, and more complete replacement. The granitoid texture is preserved by the finely divided secondary minerals.

Alteration Along Magnetite-Hematite Veins.—The granodiorite adjacent to the magnetite-hematite veins is altered for several inches. At the vein walls it has been highly silicified for distances up to four mm. and contains aggregates of muscovite and rutile. Beyond this a finely divided mass of sericite, chlorite and carbonate, has replaced the feldspars and ferromagnesian minerals, and veined the quartz grains.

Alteration Along the Gray Quartz Vein.—The dark gray quartz, as already stated, is found only in contact with remnants of the tabular body of altered granodiorite. Adjacent to the gray quartz lenses, chalcedonic quartz is developed extensively, and obscures the remaining evidence of the original character of this highly altered rock. The contacts of the quartz lenses are indefinite. Pyrite occurs with the chalcedonic quartz and is heavily disseminated in the altered granodiorite near the gray quartz lenses.

Alteration Along the White, Finely Banded, Comb Quartz Veins.—Alteration along the white, banded, comb quartz veins, is comparatively simple and not extensive. The minerals of the granodiorite are replaced mainly by chalcedonic quartz and to a

lesser extent by finely divided sericite, chlorite, and small amounts of carbonate. The hornblende and biotite are altered to chlorite, carbonate, magnetite and epidote. Silicification is predominant near the veins, and sericitization, chloritization and carbonatization beyond this. Fragments of granodiorite included in these veins are almost completely replaced by chalcedonic quartz.

Alteration Along the Late Carbonate Veins.—Alteration along the late carbonate veins is not extensive, consisting predominantly of carbonatization and chloritization, which seldom extends more than a foot into the walls. Fragments included in the carbonate veins are replaced to a variable extent by carbonate and finely divided chloride with finely divided hematite in some places.

Adjacent to pitchblende shoots, large quantities of finely divided hematite partially replace all the minerals, and particularly the feldspars, of the wall rocks for distances up to two feet, converting the granodiorite to a bright red rock. Here, pitchblende seams and replaces the minerals of the granodiorite several inches from the margin of the veins. Native silver is widely disseminated in the red rock. This red alteration accompanies all the pitchblende shoots and is absent elsewhere.

Paragenesis.

The fracture system along which the main vein lies has been the locus of several periods of mineralizing solutions and rock readjustments. The sequence of mineral deposition will be considered by the various stages already outlined.

Early Stages of Mineral Deposition.—The formation of the initial fracture occurred late in the consolidation of the granodiorite. The fracture was originally a warped surface, narrow, and uniform in width. Solutions invaded the granodiorite along the fracture altering the minerals of the granodiorite to chlorite, actinolite, epidote, hematite, magnetite, and red garnet to form one of the tabular bodies of altered granodiorite. Red garnet, actinolite and platy hematite are early. Pyrite, chalcopyrite and arsenopyrite are late minerals and may be related to the later gray quartz (Stage III). Chlorite is a persistent mineral and was deposited in large quantities at this time.

Closely following this stage, solutions deposited large quantities of hematite, then magnetite in a gangue composed of finely divided chlorite, siderite, chalcedonic quartz, epidote, actinolite, red garnet, muscovite and rutile. Chlorite is again a persistent mineral. Red garnet is early. Wall rocks are replaced largely by chlorite, siderite, and to a limited extent, by chalcedonic quartz and sericite.

The dark gray, fine-grained quartz was deposited after the formation of the tabular body of altered granodiorite, and is believed to have followed the formation of the magnetite-hematite veins also. Pyrite, arsenopyrite and chalcopyrite, in the order named, were deposited with and replace the fine grained gray quartz. Considerable silica was introduced into the wall rocks at this time.

The similarity of the minerals in the first two stages and the general occurrence of the massive fine grained gray quartz with the tabular bodies of altered granodiorite along the main zone and elsewhere in the granodiorite mass, suggests that the above three stages are related and represent successive stages in a single period of mineral deposition.

Aplite Dikes.—Narrow aplite dikes intruded along the main zone during a period of renewed movement and readjustments following the deposition of the gray fine grained quartz. Fracturing developed across a greater width.

White, Banded, Comb Quartz Veins.—Renewed movements along the warped surfaces of fracture resulted in the development of a series of lenticular openings and provided channelways for solutions from which the white, finely banded comb quartz was deposited. Wall rocks and fragments are replaced by quartz and to a less extent by sericite, chlorite and carbonate.

Chlorite and siderite were deposited in minor quantities at this stage. Hematite was deposited in large quantity; some of it was interdeposited with some of the quartz. Pyrite, an early mineral, is rare and is followed by bornite, chalcopyrite and chalcocite in the order named, although they show overlapping age relations at places; these minerals replace the quartz. It is impossible to state how much of the copper sulphides was deposited at this time and how much is related to the subsequent

period of mineral deposition, but, no doubt much of the copper sulphides that shows no direct relationship to the later carbonate veinlets, is related to this period of mineral deposition.

Late Carbonate Veins.—Following the deposition of the white banded quartz veins, the vein system was again deformed, the vein matter re-brecciated and the fracture system extended to its present width. Numerous transverse fractures developed.

Solutions introduced into this highly fractured zone deposited a variety of carbonates, small amounts of chlorite, quartz and a large variety of metallic minerals, including pitchblende and native silver. These minerals fill the transverse fractures, replace earlier vein material, cement the brecciated fragments and fill vugs in the banded white quartz veins.

The carbonates, siderite, ankerite, dolomite, rhodochrosite, and calcite, show repeated periods of mineral deposition and alternate with chalcedonic quartz. Siderite where present is the earliest, rhodochrosite is late, and calcite is invariably the last to be deposited and everywhere can be found veining and replacing the other carbonates. Small amounts of calcite generally occur with the metallic minerals in all the carbonate veins. Chlorite was deposited mainly with the early carbonates. Chalcedonic quartz is interbanded with the carbonates, and euhedral quartz crystals occur with rhodochrosite and calcite, filling vugs in the carbonate stringers.

Sufficient specimens were not examined to permit stating the sequence of deposition of all the metallic minerals in the late carbonate veins, but, the sequence of deposition of certain general groups of associated minerals can be indicated as follows:

Group I. Pitchblende, hematite, native silver (?).

Group II. Cobaltite, arsenopyrite, safflorite-loellingite, rammelsbergite, niccolite, gersdorffite, glaucodot, breithauptite, minerals *B* and *D*.

Group III. Arsenopyrite, aikenite (?), bismuthinite, famatinite and sphalerite.

Group IV. Tetrahedrite, bornite, native silver (?) chalcopyrite, chalcocite, stromeyerite, pearcite, galena, algodonite, and hematite.

Group V. Native bismuth, chalcostibite, hematite, chalcopyrite, minerals *A* and *C*.

Group VI. Native silver.

The positions of these groups are well substantiated with the exception of Group III. The minerals of this group occur in altered chloritized wall rocks near the carbonate veins, but have not been found in contact with any of the characteristic minerals of this stage and it is possible that some may be related to earlier stages of mineral deposition. They occur generally with arsenopyrite and are tentatively placed in this position.

The marked occurrence of concentrations of native silver with shoots of pitchblende in the carbonate veins, their association, replacing minerals of the wall rocks, and the zonal distribution of native silver and calcite around fronds of dendritic pitchblende in siderite suggest a close relationship in time of deposition of some of the native silver with the pitchblende. Native silver is, therefore, indicated in Group I with the pitchblende.

Native silver is commonly present with bornite and forms "emulsion" intergrowths with that mineral. Chalcocite, which shows overlapping age relations with the bornite, contains unmixed stromeyerite. It is evident, therefore, that the solutions contained silver at the time of deposition of these minerals. Further evidence is found in the occurrence of pearcite with the copper sulphides. The possibility that some native silver was deposited at the time of deposition of these minerals can not be ruled out in the absence of definite evidence and native silver is therefore tentatively included in Group IV.

The minerals in Group V occur with native bismuth in persistent carbonate and quartz stringers which formed late in this stage.

Temperature of Formation.

Minerals deposited during the early period of mineral deposition, such as red garnet, actinolite, epidote, magnetite, muscovite, rutile and arsenopyrite indicate that the solutions which circulated along the fracture system at this time were at quite elevated temperatures. The early minerals of this stage may be classed as pneumotectic, the later minerals as hypothermal.

Intrusion of the aplite dikes followed the above period of mineral deposition and marked the introduction and deposition of minerals at magmatic temperatures, above 573° C., at this time.

The presence of bornite, chalcopyrite and isometric chalcocite in the banded white quartz veins indicates mesothermal temperature conditions prevailed at the time of their formation.

Several mineralogical features of the late carbonate stage of mineral deposition provide information regarding the temperatures at that time. The chalcocite is isometric and, therefore, formed at a temperature above 91° C. The bladed structure of unmixed stromeyerite in the chalcocite indicates this mineral has inverted from orthorhombic to isometric stromeyerite at a temperature near 93° C. and was deposited at some temperature above this.

Native bismuth has a melting point at 271° C., therefore, the temperature at the time of deposition of this mineral was below 271° C.

The native silver has a coarse homogeneous recrystallization texture, indicating the silver was deposited at a temperature above 200° C., its recrystallization temperature.

Pitchblende, the cobalt-nickel minerals and arsenopyrite are generally considered as "high temperature" minerals. However, in the late carbonate veins they occur as skeletal crystals or have colloform and dendritic structures; rarely are they well crystallized. These structures, it has been shown, can develop from ionic and colloidal solutions in a gel.[14] Because fundamental data are lacking as to the temperatures of coagulation and stability ranges of such solutions, too much weight cannot be placed upon these minerals as temperature indicators.

The general mineralogy and the temperature conditions outlined, indicate that the minerals of the late carbonate veins were deposited under mesothermal to epithermal conditions.

[14] Jolliffe, F. T.: M.Sc. Thesis, Department of Geology, Queen's University, Kingston, Ontario, 1931.

Nature of the Solutions.

The presence of large quantities of micas, epidote, and other hydrous minerals indicates the high temperature solutions of the early stages were hydrothermal. The solutions initially were supersaturated with respect to magnesium, calcium, iron and oxygen. In later stages of this period they became predominantly silicic and supersaturated with iron and sulphur and towards the end the solutions were saturated to a limited extent with arsenic and later, copper.

The solutions of the white banded comb quartz stage were highly silicic and hydrothermal in nature. They contained iron, copper, calcium, magnesium, sulphur and limited quantities of carbon dioxide. The zonal distribution of tiny inclusions in the quartz resulting in rythmic banding, and the colloform habit of much of the hematite, suggest that the solutions may have been in part colloidal.

The solutions from which minerals of the late carbonate veins were deposited, were hydrothermal, exceedingly rich in carbon dioxide and contained limited quantities of silica. Insufficient data are available to state the changes that occurred throughout the deposition of the various metallic minerals. The solutions contained manganese, iron, magnesium, calcium, sulphur, arsenic, cobalt, nickel, copper, bismuth and silver, smaller quantities of uranium and antimony, and were comparatively poor in zinc and lead.

Many of the minerals of the late carbonate veins occur as skeletal crystals, or have colloform and dendritic structures, which, as stated, can develop from ionic and colloidal solutions in a gel. The analysis of the spherulitic pitchblende confirms microscopic evidence of the presence of appreciable quantities of finely divided impurities. All these facts suggest that the solutions were to a considerable extent colloidal. However, until such time as the existence of colloidal solutions under elevated temperatures and in complex systems is demonstrated, and the stability ranges of colloidal forms of the various minerals is determined, it is difficult to determine to what extent colloidal solutions were active during the deposition of the minerals of these veins.

The elevated temperatures of formation of each of the stages indicate that the solutions in every case were of hypogene origin. The indicated temperature of deposition of the silver and the presence of a small amount of mercury indicate that the silver is largely hypogene. Some leaf silver may be supergene.

AGE OF THE PITCHBLENDE.

The lead-uranium ratio in the pitchblende of this deposit has been determined as 0.083.[15] According to the time scale compiled by the Committee on the Measurement of Geologic Time,[16] this ratio would place the age at around 650 million years, approximately that of the Killarney granite in the North Shore of Lake Huron area, Ontario, or Keweenawan in age.

GENESIS.

Three igneous intrusives are exposed in the Great Bear Lake area, the granodiorite, the pink biotite granite and the late quartz diabase dikes and sills of probable Keweenawan age, one of which may be the source of the silver and pitchblende.

The three early stages of mineral deposition have been shown to be closely related to one another in time and source, and to be genetically related to the granodiorite. Evidence has been presented to show that the vein material formed during this early period was deposited prior to the deformation that preceded the aplite dikes and the white banded quartz veins.

The white banded quartz veins of the deposit are later than the aplite dikes and show marked textural and mineralogical similarities to a vast number of finely banded white comb quartz veins that are widespread in both the granodiorite and the pink biotite granite. They must, therefore, be related to the pink biotite granite or to some intrusive younger than the biotite granite.

Since the silver and pitchblende occur in the late carbonate veins that followed a period of deformation subsequent to the

[15] Hecht, F.: Vienna, personal communication, 1935, courtesy Professor A. C. Lane, National Research Council, Washington, D. C.

[16] Report of the Committee on the Measurement of Geologic Time. Nat. Res. Coun., Wash., April, 1934, p. 1.

formation of the banded white comb quartz veins, the granodiorite is eliminated as a possible source of these minerals.

The Thompson Group of claims is located on the southwest side of Contact Lake and east of Bow Lake, Fig. 1. In the pink biotite granite, which underlies the claims, three quartz diabase dikes lie parallel, and are mineralogically similar, to the dike that lies along the north shore of Contact Lake. These are members of the late group of diabase dikes and sills of Keweenawan age. White finely banded comb quartz veins carrying hematite and copper sulphides are widespread on these claims. They cut the diabase dikes and lie along sheared zones in them.[17] One such vein in the large quartz diabase dike, one and a half miles from the "B.E.A.R." deposit, is mineralized with hematite, pyrite, bornite, chalcopyrite and siderite and is cut at a large angle by a vein containing pink calcite, siderite, quartz, cobalt-nickel arsenides, pitchblende and silver.

The evidence indicates that the widespread group of white, finely banded comb quartz veins mineralized with hematite and copper sulphides is younger in age than the late quartz diabase dikes, and that here, as in the "B.E.A.R." deposit, deformation followed the formation of the white banded comb quartz veins and in turn was followed by the deposition of pitchblende, silver, and cobalt-nickel arsenides in a carbonate and quartz gangue.

It is evident that the silver, pitchblende and associated minerals of the two deposits in the vicinity of Contact Lake were formed subsequent to deformation that followed the formation of the white finely banded comb quartz veins, and are younger in age than the late quartz diabase dikes and sills of probable Keweenawan age.

The age of the gently dipping quartz diabase dike at Labine Point, as determined by the helium, radium, and thorium ratio, is 565 million years.[18] The age of the pitchblende in the "B.E.A.R." deposit, as determined by the lead-uranium ratio is

[17] Horwood, H. C.: Personal communication, January, 1935.

[18] Lane, A. C.: Personal communication, March 1935. Analysis of specimen by Dr. W. D. Urry, Mass. Inst. of Technology, Cambridge, Mass.

approximately 650 million years.[8] Both age determinations fall within the time limits determined for the Keweenawan Period.[5]

GENERAL RELATIONS.

The region extending from Workman Island, 20 miles north of Contact Lake to Beaverlodge Lake, 100 miles south of Contact Lake comprises a small area in a petrogenic province. It has a widespread distribution of mineral deposits containing among other elements members of a characteristic group consisting of pitchblende, silver, cobalt, nickel and bismuth and may, therefore, be regarded as a metallogenic province, the boundaries of which have not yet been established.

It is significant that in all occurrences in this metallogenic province, where the relationship of the pitchblende, silver and associated cobalt, nickel and bismuth minerals, to either the late quartz diabase and related dikes of probable Keweenawan age, or to the late banded comb quartz veins, is clearly exhibited and not obscured by the presence of earlier periods of mineral deposition, these minerals are younger in age and have been deposited subsequent to deformation following the consolidation of the diabase dikes and the banded comb quartz veins. These occurrences are as follows:—the deposits at B.E.A.R. and the Thompson group of claims, Workman Island deposit,[19] three deposits at Beaverlodge Lake, namely (1) Tatee Claim,[20] (2) Bee No. 3 Claim,[21] (3) W.L.O. and W.K. Claims,[22] Rainy Lake occurrence [23] and at Gunbarrel Inlet, 30 miles south of Contact Lake. At the head of Gunbarrel Inlet, a low dipping sheet of diabase over 300 feet thick intrudes the southern extension of the Dowdell Point granite mass.[24] Six miles eastnortheast of here a mass of this diabase lies across the contact of the biotite granite and older

[19] Kidd, D. F.: Rae to Great Bear Lake, Mackenzie District, N.W.T., Bur. Econ. Geol., Canada, Mem. 187: 40, 1936.

[20] Kidd, D. F.: Idem, pp. 26 and 27.

[21] Kidd, D. F.: Idem, p. 28.

[22] Kidd, D. F.: Idem, p. 29.

[23] Furnival, G. M.: Silver mineralization at Great Bear Lake. Can. Min. Jour., 55: 7, 1934.

[24] Kidd, D. F.: *Op. cit.* p. 13.

volcanic rocks. It is in general lithologically similar to the late gently-dipping quartz diabase dikes of the Echo Bay district. Fractures in the diabase at the head of Gunbarrel Inlet are filled with calcite seams carrying native silver and cobalt minerals.[25]

The mineralized zones in the remaining occurrences of the region have not been found directly in contact with either the late diabase intrusives or the late banded comb quartz veins. It seems evident, therefore, that the burden of the proof that a genetic relationship exists between the pitchblende, silver, cobalt, nickel and bismuth minerals, and intrusives older than the late diabase intrusives rests with those who support this view. Satisfactory proof of this view has not yet been presented.

Regarding the age of the pitchblende, silver and associated minerals of the Eldorado mine, Kidd points out that pitchblende occurs in one of the mineralized zones, where it crosses an aplite dike related to the pink biotite granite on the west side of Labine Point, thus making the pitchblende and associated minerals younger than the granite.[26] Then, largely on the basis of the occurrence of small amounts of fluorite in the mineralized zones and in two out of seven sections of the biotite granite, he states that it is possible that the pitchblende and silver deposits are co-magmatic with the granite. Elsewhere he states that these fracture zones have been the locus of earlier mineralizing solutions related to the older granodiorite intrusives.[27] It is to be expected that volatile constituents of the later biotite granite would find their way into these pre-existing, mineralized zones along which still later solutions could deposit the pitchblende, silver and other minerals. The presence of the fluorite may indicate only that some minerals in the deposit are co-magmatic with the biotite granite.

It is significant that the deposit at the Eldorado mine, the most important deposit in the area, occurs only a few hundred feet below the late gently dipping diabase dike or sill at a point where it forms an anticlinal structure. It is further significant that in

[25] Furnival, G. M.: *Op. cit.*, p. 7.

[26] Kidd, D. F., and Haycock, M. H.: Mineragraphy of the ores of Great Bear Lake. Bull. G.S.A., 46: 936, 1934.

[27] Kidd, D. F., and Haycock, M. H.: *Op. cit.*, pp. 891 and 938.

the important deposit on the Echo Bay group of claims only a hundred feet or so above this same intrusive, there is evidence of one and possibly two early periods of mineral deposition, where, Kidd states, pyrite, arsenopyrite, chalcopyrite and possibly sphalerite, galena, and bornite, were deposited, with extensive replacement of the wall rocks, and that the mineralized zones then were subjected to deformation, subsequent to which, carbonate veins were deposited with niccolite, cobalt-nickel minerals, chalcopyrite, galena and silver minerals.[28]

CONCLUSION.

The silver and pitchblende in the " B.E.A.R." veins were deposited following deformation subsequent to the deposition of white, finely banded comb quartz veins carrying hematite and copper sulphides, which are younger than the late quartz diabase dikes and sills of probable Keweenawan age.

Evidence from a large number of occurrences in the metallogenic province of which the " B.E.A.R." vein is a member, indicates that the silver and pitchblende of these deposits were likewise deposited after deformation subsequent to the formation of finely banded white comb quartz veins that are younger than the late diabase intrusives.

The silver and pitchblende are either co-magmatic with the late quartz diabase dikes and sills of probable Keweenawan age, the youngest exposed intrusives in the region, or are related to some younger, unexposed intrusive.

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[28] Kidd, D. F., and Haycock, M. H.: *Op. cit.*, p. 887.

METASOMATISM OF COUNTRY NEAR ORE-BODIES AND ITS POSSIBLE ECONOMIC SIGNIFICANCE.

E. de C. CLARKE AND H. A. ELLIS.

This paper was read as the opening contribution to a discussion on the above subject at the meeting of the Australasian Association for the Advancement of Science held at Canberra, A.C.T., Australia, in January 1939.

The authors have endeavored to point out the economic value of a quantitative and comparative study of metasomatism, and have summarized knowledge concerning this subject in its bearing on gold deposits in Western Australia.

It is hoped that it will be found possible to conduct future investigations on this problem along lines somewhat similar to those suggested here.

INTRODUCTION.

EVERYONE knows the term "kindly country" as used by miners and prospectors. Sometimes one part of an area is said to be "kindly" because it differs lithologically from another part, which is "unkindly." Thus, in Western Australia (and all our subsequent remarks apply only to gold mining in Western Australia), "greenstone" country (*i.e.* country comprised of ancient basic igneous rocks) is "kindly" for gold, whereas granite country is "unkindly." But the experienced prospector goes further than this—the presence of certain igneous intrusions in a greenstone area tells him that it is kindlier country than a greenstone area devoid of such intrusions. Further, other things being equal, he knows that a greenstone area that is soft and schistose is kindlier than one that is hard and blocky, and, going into still more detail, he will prefer one area of schistose greenstone to another perhaps because it has more "kaolin" or shows little seams of "ironstone," or, in the unoxidized zone, because of some perhaps scarcely definable difference in the grains of pyrite. In short, the experienced prospector regards as reliable indications, first the lithology, second the structure, third the mineralogy, of the country near the lode. The lithological factor is the domi-

nant one; for example, an area of sheared and sericitized granite is not kindly—the favorable structural and mineralogical features are altogether neutralized by the dominating fact that lithologically the country is unkindly. Further than this, the man of wide experience knows that what are unfavorable indications in one district are not necessarily unfavorable in another.

Mining geologists have, to a certain extent, systematized accumulated experience into such statements as "Important gold bodies occur in certain types of greenstone and are situated in definite positions structurally"—for example, in one district, on the limbs of minor folds that cross the main structures. But everyone knows that, given these favorable conditions of lithology and structure, ore-bodies will not necessarily occur, nor can one be sure that, if ore-bodies do occur, they will be much good.

The purpose of this discussion is to find out whether it would not pay to give more attention to that third factor—to the degree and kind of metasomatism that has affected the country. In a given area, favorable lihologically and structurally, is it not possible that from degree and kind of metasomatism one could deduce with fair certainty whether ore-bodies do exist before they are looked for by the expensive methods of mining?

Metasomatism may be defined as the name given to the chemical processes, involving the introduction and removal of matter, which result in minerals being changed to others of different chemical composition.

Most ore deposits of the lode or vein type are bordered by a strip of country in which certain metasomatic changes have taken place. Silicification, tourmalinization, sericitization, carbonatization, and biotitization are examples of such metasomatic changes. There may be, also, progressive changes in the mineralogical composition of the country as the ore-body is approached.

If, in a certain mine, it had been shown that a certain progression of mineral changes always took place in the country bordering on rich shoots, then, if this progression was encountered in exploratory work one would surmise that another shoot was nearby. Of course degree and kind of metasomatism will

depend *in part* on the lithology and structure of the country, because the same metasomatizing agents will vary in their effects according to the varying physical and chemical characteristics of the rocks.

To discuss *whether,* on theoretical principles, there should be such variations in metasomatism bordering on different parts of the same ore-body is, we think, not our concern in this discussion. It seems likely that, by the patient amassing and sorting of *facts* (not theories), regarding type and degree of metasomatism associated with known ore-bodies we should be able to arrive at some generalizations that would lead to greater economy and certainty in prospecting, particularly in underground prospecting by crosscutting and diamond drilling.

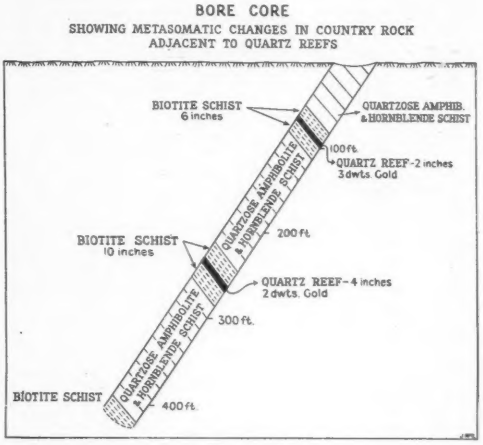

FIG. 1.

In an instance which has recently come under the writers' notice, a strong development of biotite occurs in the wall rock of a body of auriferous quartz, which is being profitably mined. In an attempt to locate other ore-bodies near the known one, diamond drill holes were bored from the surface (Fig. 1), and in one of these the last few feet of the core showed biotite, yet boring was

discontinued. Several thin veins (up to 2 inches) of auriferous quartz had been passed through in the upper section of the borehole, and biotite appeared in the wall rock for short distances on both sides of them. Whoever was conducting that boring campaign had failed to realize the significance of a metasomatic development of biotite in the wall rock adjacent to the deposit, and boring was stopped just where indications were favorable.

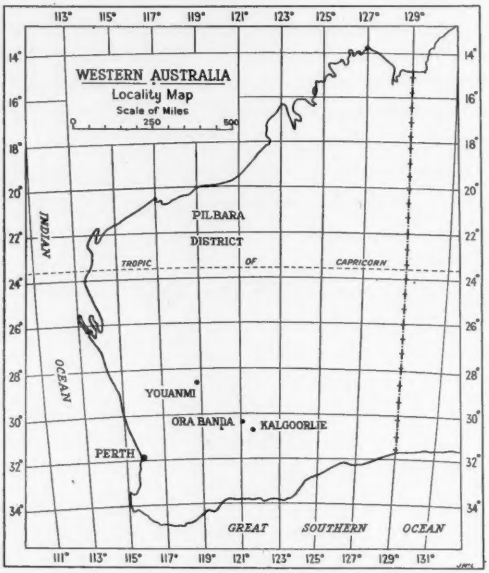

FIG. 2.

More facts about metasomatism are needed if it is to be of service to mining. It must be studied near lean as well as near rich sections of an ore-body, and the study should have as its object the determination of quantitative chemical and mineralogical data without questioning the nature and origin of the metasomatizing agents.

The generalizations obtained from a comparative study of

these data in any one mine, may be found to be applicable to a group of mines in the same locality, and it may be possible to advance from localities to a whole district, if it is uniform in structure and lithology.

STUDIES OF METASOMATISM IN WESTERN AUSTRALIA.[1]

If there is any Western Australian mining area that should present evidence for or against the usefulness of a study of metasomatism it ought to be Kalgoorlie—the most intensively mined, geologized, and discussed district in the State. The latest and most detailed study of a part of this area is contained in a bulletin [2] of the Geological Survey of Western Australia, which is as yet unpublished. The following sketch of the area is based on Mr. Feldtmann's work.

The geological history and table of rock-succession is lengthy and involved, but, so far as the main mining area is concerned, the oldest rocks are the "Older Greenstones." They include fine-grained amphibolites, fine-grained greenstones, and calc-schists, and are an assemblage of Archæozoic basaltic lavas (in many places showing pillow structure) with, probably, some pyroclastics.

The Older Greenstones were succeeded by a series of sediments, tuffs, and lavas, of varied composition, which has been termed the Black Flag Series by H. W. B. Talbot. Two or three formations were then accumulated which have not been preserved in the Kalgoorlie area itself but which are to be found not many miles away. Then came the invasion by the "Younger Greenstones," which range in composition from quartz-gabbro to peridotite. Almost everywhere the Younger Greenstones are metamorphozed, the least altered types being epidiorite, hornblendite and serpentine.

The next younger series, and the last of prime importance in the principal mining area, are a number of dikes of intermediate composition, ranging from porphyrite to albite porphyry. They

[1] Localities shown on Fig. 2.

[2] Contributions to the Study of the Geology and Ore Deposits of Kalgoorlie, Part IV, by F. R. Feldtmann.

are thought to be differentiates of the magma that yielded the Younger Greenstones.

Intervening between, or accompanying the emplacement of these various rock-assemblages, there were repeated earth-movements by which the bedded rocks were folded, and both they and the massive rocks were sheared and jointed to various degrees. The structures so imposed on the rocks probably provided access for gaseous and liquid emanations that caused propylitization throughout a long and somewhat irregular belt. Propylitization took place shortly after the porphyrite invasion and may be called the first phase of the metasomatism. After propylitization had proceeded for some time, renewed earth-movement caused the formation of shear-zones, particularly in the Younger Greenstones. Afterwards the emanations changed, becoming poor in CO_2 and rich in silica, sulphur, and potash, and also carrying gold. Wherever the emanations of this second phase penetrated, they not only deposited gold but also formed minerals containing silica, sulphur, and potash, so that the lodes generally vary in richness directly as their content of pyrite, sericite, and secondary quartz. Thus, the second phase formed the lodes and also formed, metasomatically, new minerals in the rocks that lay in and near the lode channels. It was followed, apparently without any break in time, by a third phase of emanations carrying tellurium compounds and gold, which did not penetrate nor metasomatize the country, but were deposited wherever there was any space.

It should be remembered that there were many other incidents in the story as worked out by Mr. Feldtmann, and there is danger that, in such a drastically condensed account, some events of importance to this discussion have been slurred over or omitted. However, this portion of our contribution has been read and amended by Mr. Feldtmann—a courtesy for which we are very grateful—and it represents his interpretation as fairly as could be done in such a small compass. Mr. Feldtmann is anxious that we should make it clear that the true character of the original rocks and the fact that the Kalgoorlie rocks have in places been profoundly altered by metasomatism were very clearly demon-

strated by Simpson[3] in 1912. Advances on the lines laid down by Simpson were made by Thomson, by Larcombe, by Feldtmann[4] and by Stillwell.[5] However, Feldtmann's latest unpublished work presents a greater wealth of evidence than had previously been collected.

Metasomatism at Kalgoorlie has been discussed by Feldtmann and the other investigators, but, so far, not much has emerged that can be applied practically. It appears as if structure and rock-type have been the important factors in localization of rich ore. Metasomatism in the form of propylitization is certainly an almost invariable accompaniment of ore-formation at Kalgoorlie, but it does not seem as if the richness of the lodes is necessarily reflected in the intensity of the first phase of the metasomatism. Investigations indicate that lodes are poor where the enclosing rock is highly chloritic, *i.e.* where it has only undergone a minor amount of carbonatization, and that the richer ore-bodies are invariably in rock that has been highly carbonatized; unfortunately it is not the case that *every* area of highly carbonatized rock contains rich lodes.

The degree of the intensity of the sericitization that took place during the second (gold-deposition) phase of metasomatism seems to reflect the richness of the lode more truly than any other type of alteration, but, as sericitization is generally confined to the lodes themselves and does not extend to the country, this feature is of no value in the search for ore-bodies.

Variation in magnetite content of the country has also been found by Feldtmann to vary directly with variation in the richness of lodes. He comes to the conclusion, after the examination of many thin sections, that the considerable variation in iron-percentage in the unmetasomatized quartz-dolerites is responsible for the equally wide variation in amount of secondary magnetite that was formed by propylitization.

Magnetite, he considers, was the mineral that reacted with the

[3] Geol. Surv. West. Aust. Bull. No. 42, 1912.
[4] Geol. Surv. West. Aust. Bull. No. 69.
[5] Geol. Surv. West. Aust. Bull. No. 94.

sulphur, in the later gold-precipitation phase of propylitization, to form pyrite. It follows that magnetite should be strikingly abundant in the metasomatized rock near the richer parts of an ore-body—in those parts, that is, which were too far away from the channel along which the gold-bearing solutions were travelling, to be pyritized by them. In confirmation of this more or less "theoretical" reasoning, Feldtmann notes that there is a fairly marked association of richer portions in the "X" and "B" lodes near the Perseverance—Great Boulder boundary and of the Enterprise main lode, with highly carbonatized rock containing abundant magnetite. It must be noted, however, that the absolutely final, tellurium-bearing emanations, which formed rich patches of telluride ore, did not effect any metasomatism. Consequently, patches of such final phase ore often, according to Feldtmann, lie in a matrix that is indeed highly altered but yet, right alongside of the lode, contains much magnetite and no pyrite.

Feldtmann's unpublished bulletin contains a section on "The Economic Significance of the Rocks," which shows that a geologist, thoroughly familiar with the rocks of the area, might form an opinion, from the mere aspect of the country, whether or not a lode was likely to be payable. There is no doubt that in arriving at this opinion, the geologist would be guided not only by structure and a knowledge of the petrological classification of the rocks but also by the character of the metasomatism.

Dr. R. T. Prider informs us that he has noticed at Kalgoorlie that the small, rich ore-bodies occur in the narrower zones of highly carbonatized rock, which pass abruptly into rock that is but slightly carbonatized, whereas the larger, lower grade bodies, lie in wider zones that grade gradually into comparatively uncarbonatized rock.

We are indebted to Mr. K. J. Finucane for the following notes on Kalgoorlie:

> The extent of metasomatism throughout the Kalgoorlie Belt makes it difficult to define any hard and fast rules for the occurrence of payable ore shoots within particular types of metasomatized country.
>
> The degree of carbonatization of the rocks is often a useful guide to

the presence of ore, but there are many large carbonatized areas which do not contain payable shoots. Furthermore, many instances could be cited of the occurrence of rich shoots in more or less unaltered quartz dolerite greenstone.

On the Great Boulder and Horseshoe Mines the degree of alteration in the vicinity of portions of the Main Lode is such that the original character of the wall rock is difficult to determine. In such places the walls consist of a fine-grained rock, composed of quartz, sericite and carbonates, which may be altered greenstone or altered acid dyke. The presence of this material in crosscuts or diamond drill holes indicates close proximity to the lode, the grade of which is usually high.

Summing up the evidence from Kalgoorlie, practically all the ore-bodies are in metasomatized country, but the only features of metasomatism, so far as we know at present, which indicate the probable character of the lode, are the degree of sharpness with which metasomatized is demarcated from unmetasomatized country, and the abundance or scarceness of chlorite and of magnetite in the metasomatized country.

Some interesting observations on metasomatism at Ora Banda (40 miles N.W. of Kalgoorlie) were made by Simpson.[6] The specimens were collected by the author of the Bulletin (Mr. J. T. Jutson) to illustrate "passage from a massive, non-auriferous rock into sheared 'lode formation.'" Owing to lack of extensive and deep workings the investigation had to be made on specimens from a depth of only about 240 feet, and it was not possible to get a complete sequence from one crosscut. The specimen of unaltered country rock was obtained in the Victorious G. M. (about 10 chains south of the Gimlet) from which, in one crosscut that appears from the plan to be only 15 to 20 feet long, were obtained three specimens: one of "auriferous lodestuff (metasomatized hornblende porphyrite)," another of "massive porphyrite on the boundary of the lode, distinctly affected by the agencies of ore deposition," and another, which was the least altered, at an unspecified distance from the ore-body. Simpson examined these specimens microscopically and analyzed them. A graphic comparison of the most interesting features of the analyses is shown in Fig. 3, which also shows the mineralogic changes as determined by Dr. R. T. Prider by micrometric analyses of

[6] In Geol. Surv. West. Aust. Bull. No. 54, 1914.

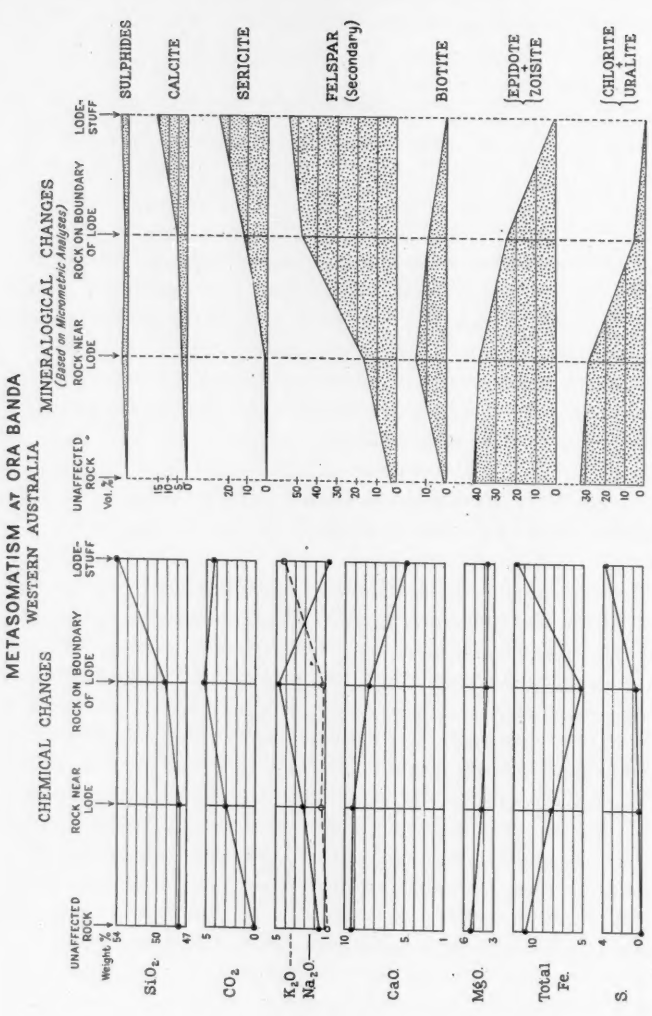
METASOMATISM AT ORA BANDA
WESTERN AUSTRALIA.
CHEMICAL CHANGES
MINERALOGICAL CHANGES
(Based on Micrometric Analyses)
UNAFFECTED ROCK
ROCK NEAR LODE
ROCK ON BOUNDARY OF LODE
LODE-STUFF
Weight %
Vol. %
SiO2
CO2
K2O
Na2O
CaO
MgO
Total Fe.
S.
SULPHIDES
CALCITE
SERICITE
FELSPAR (Secondary)
BIOTITE
EPIDOTE + ZOISITE
CHLORITE URALITE

FIG. 3.

the rock sections. We are greatly indebted to Dr. Prider for this material assistance. Note the steady rise in silica from 48 to 54; CO_2, K_2O, and S also show increases from the country into lode, although these increases are by no means regular; on the other hand there is a falling off in lime, and magnesia. The curve for total iron with its decrease toward the lode and its increase to the original amount where the lode is entered, is hard to reconcile with Feldtmann's interpretation of the magnetite-pyrite relations. It must be remembered, however, that the Ora Banda results are based on four specimens only, and that Ora Banda is many miles from Kalgoorlie—hardly in the same "district."

In the petrological examination quartz was not determined. The most striking feature is the increase in feldspar, which is considered to be practically all secondary. The increase in colorless at the expense of colored minerals is very marked, also the increase in biotite on nearing the lode and its decreasc in the lode itself. Sericite shows a gradual and constant increase from the country into the lode and calcite and sulphides also increase.

Except for these investigations we are not aware of any publications that deal in any detail with the phenomena of metasomatism in the vicinity of Western Australian ore deposits, or make any attempt at a quantitative treatment. There are frequent references to the fact that metasomatism does occur, but nothing that seems to bear on the problem under discussion.

Mr. R. W. Fletcher has very kindly supplied some information regarding the ore occurrence at Youanmi (about 200 miles N.W. of Kalgoorlie) from which it seems (Fig. 4) that the lode, 4 to 10 feet wide, is bordered by 16 to 20 feet of carbonatized chlorite schist, which is sharply marked off from the generally massive, but in places, slightly sheared, epidiorite, which forms the country. Mr. Fletcher notes that in places where the schist is strongly carbonatized the gold content seems to fall off, whereas antimony and arsenic sulphides are abundant in good lode matter.

Mr. K. J. Finucane has kindly supplied the following notes on recent observations in the Pilbara Goldfield:

FIG. 3.

Investigations carried out by the Northern Australia Survey in the Pilbara District during the past four years have shown that the majority of the larger gold mining centers in that district occur in the Warrawoona Series, which consists mainly of basic and acid lava flows (including pillow lavas) with interbedded quartzites and carbonatized chloritic and

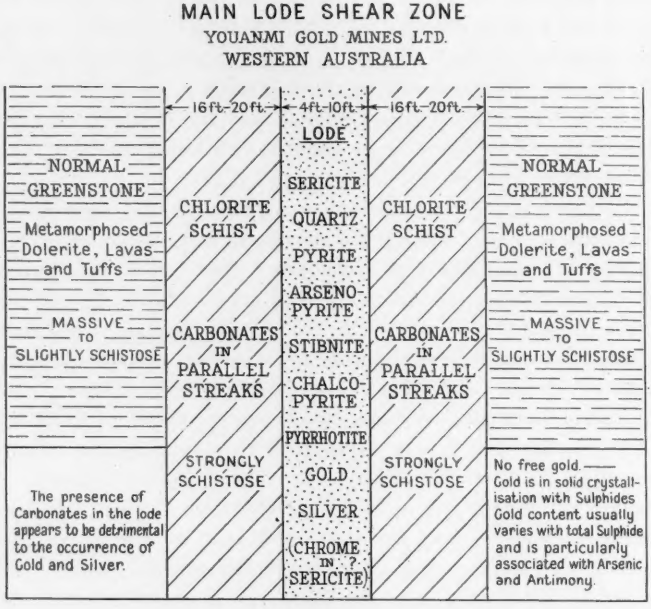

FIG. 4.

chlorite-magnetite schists. Gold-bearing quartz reefs in this series are associated commonly, although not always, with highly carbonatized areas of basic schists and carbonatization of the adjacent country rock appears to have been a common phase of gold mineralization. The extent of the carbonatization is in many cases roughly proportional to the size and value of a particular center or particular deposit. In the larger centers the extent of carbonatized rocks is considerably greater than in centers of less importance.

Reefs and lodes occur in areas of carbonatized schists at Bamboo Creek, Halley's Comet, Lalla Rookh, Marble Bar, and several smaller centers. In many of the minor fields in the Pilbara District where the rocks are less altered, the reefs are found to be relatively smaller, and the shoots of ore shorter.

In conclusion, quoting almost verbatim from E. Y. Dougherty [7]

Everyone concerned with economic geology feels the need of more facts, more established principles, more correlation and co-ordination, more synthesis. "Where it is there it is" expresses the uncertainty regarding causes of gold localization, and this is due to incomplete accumulation of facts and inadequate correlation of known facts. We should collect and compare facts from area to area and from mine to mine. To make phenomena of metasomatism of use in mining it is necessary that we should correlate gold occurrence with such well known processes as carbonatization, albitization, sericitization, and chloritization of wall rocks. It is believed that the relative intensity and character of these alterations is reflected in the variable gold-content of many mines and districts. Comparative study would bring to light more clearly the extent to which various alterations can be regarded as indicative of the productivity of ore-bodies. Comparison of gold-content where wall rock alteration has been weak with gold-content where such alteration has been strong and correlation of gold-content with kinds of alteration should be made between districts, mines, and mineral bodies in the same mine.

UNIVERSITY OF WESTERN AUSTRALIA,
AND
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA,
June 12, 1939.

[7] Econ. Geol. 30: 879, 1935.

MANGANESE MINERALIZATION AT TOMBSTONE, ARIZONA.[1]

CHARLES ALFRED RASOR.

ABSTRACT.

Irregular, rudely circular pipe-like bodies of manganese oxides have been mined at the intersection of northeast-trending mineralized fissures and steep faults in Upper Paleozoic limestones. These bodies of ore were mined principally for the silver content, but some were sufficiently large to be mined for manganese alone. The silver values were confined to the core which consisted generally of a soft and porous mass of iron and manganese oxides with variable quantities of lead and zinc oxides. Surrounding this elongated core was a hard, compact envelope of black manganese oxides; chiefly psilomelane and polianite.

The part played by sulphate solutions in the formation of the manganese oxides seems to have been ignored generally. Where deposits of manganese oxides like those at Tombstone, Arizona, are known to have been derived from the sulphide, alabandite, in association with sulphides of iron, copper, lead, and zinc, it is believed by the writer that the manganese sulphide was oxidized, the manganese taken into solution as the sulphate and transported or moved in some manner to the limestone walls to be later deposited as compact masses of psilomelane, polianite, and minor manganese oxides.

INTRODUCTION.

MANGANESE oxides are common constituents of many silver-bearing veins in the Tombstone district. Some bodies of manganese oxides were sufficiently large to be mined for manganese alone, but the greater number were mined principally for their silver content. The silver content of the manganese oxides under discussion is practically nil in comparison to that found in the soft cores of these bodies and consequently little discussion will be given to the silver question.

The original mineral, from which the manganese oxides were derived, was the uncommon manganese sulphide, alabandite. Under the influence of oxidation processes, the manganese went

[1] Published by permission of the Director, U. S. Geological Survey, and the Director, Arizona Bureau of Mines and Geology.

into solution as a sulphate, rather than a bicarbonate as is generally considered and moved downward and laterally as the sulphate until precipitated by reaction with the limestone walls into the various manganese oxides.

GENERAL DISTRIBUTION.

Manganese-oxide ore bodies are found in two narrow zones,[2] partially surrounding the rich gold-silver-lead center of mineralization. The Lucky Cuss, Escondido, Wedge, McCann, and Luck Sure ore bodies form a north-south zone near the contact with a granodiorite intrusive and were mined for both manganese and silver-bearing manganese ores. The Oregon-Prompter, Telephone, Emerald, Bunker Hill, and Mammoth ore bodies form a second group along the east-west Oregon-Prompter fault. Little mineralization extends beyond these two zones.

The semi-peripheral arrangement of the manganese deposits around the gold-silver-lead center is not treated here, but it is known that localization of the manganese ore bodies was caused by a definite structural control. Irregular but rudely circular, pipe-like bodies of manganese oxides occur at the intersection of northeast ore-bearing fissures with both the east-trending Oregon-Prompter fault and the north-trending Lucky Cuss fault in the steeply folded Upper Paleozoic limestones. Smaller ore bodies occur at the intersection of the same ore-bearing fissures with less conspicuous slip planes parallel to the two major faults.

Many of the larger ore bodies ranged from 10 to 20 feet in diameter and extended from the surface to depths of more than 700 feet. Underground workings did not reveal any mineralization such as traces of manganese oxides, that would suggest nearness to an ore body. It seems, therefore, that the manganese solutions did not travel far from the local centers of mineralization.

Psilomelane is the abundant mineral of the pipe-like ore bodies, but polianite, pyrolusite, manganite, hetærolite, and earthy black

[2] Butler, B. S., Wilson, E. D., and Rasor, C. A.: Geology and ore deposits of the Tombstone district, Arizona. Arizona Bur. Mines and Geol. Bull. 143, 1938. See Plate VII.

wad occur in minor quantities. Quartz, calcite, and hydrous iron oxides are common minerals that are found in the soft, porous cores.

MINERALOGY.

The mineral assemblage is much the same in most of the manganese deposits, consisting of the same manganese oxides. In the Lucky Cuss mine, however, geological conditions were more favorable for survival of the original minerals. They are the rare mineral alabandite, galena, tetrahedrite, sphalerite, pyrite, and chalcopyrite. Oxidation products of all these minerals are, also, present. Only the manganese minerals will be discussed.

Alabandite, MnS, is the only know hypogene manganese mineral from the district. Moses and Luquer [3] described it as occurring in large masses along the footwall of the Lucky Cuss fault fissure in pure white crystalline limestone. Specimens of alabandite found recently on the dump of the mine show much oxidation to brown and black coatings indistinguishable from the common manganese oxides. On freshly broken surfaces, the alabandite appears as brilliant black grains disseminated in a gray calcite. Microscopic examination of the specimens and of two other specimens in the Mineralogical Museum at the University of Arizona revealed the absence of other sulphides except tiny blebs of chalcopyrite. It is likely that alabandite is a late sulphide in the hypogene mineral sequence of the district.

A rare zinc manganate, *hetærolite,* $ZnO.Mn_2O_3$, was identified by the writer in ore specimens from the Lucky Cuss mine. Polished sections and microchemical analysis aided in its identification. Its occurrence as irregular veinlets and stringers in manganite and in another manganese oxide still unidentified (Figs. 1, 2, and 5) indicate a late order of deposition. It is dark gray, has high relief and reddish-brown internal reflection. Etch reactions for the Tombstone hetærolite agree closely with those given by Orcel and Pavlovitch.[4] Since there is a lack of

[3] Moses, A. J., and Luquer, L. McI.: Alabandite from Tombstone. School of Mines Quart., 13: 236–239, 1892.

[4] Orcel, J., and Pavlovitch, St.: Les caractères microscopiques des oxydes de manganèse et des manganites naturels. Soc. franç. miner. Bull., LIV: 108–179, 1931.

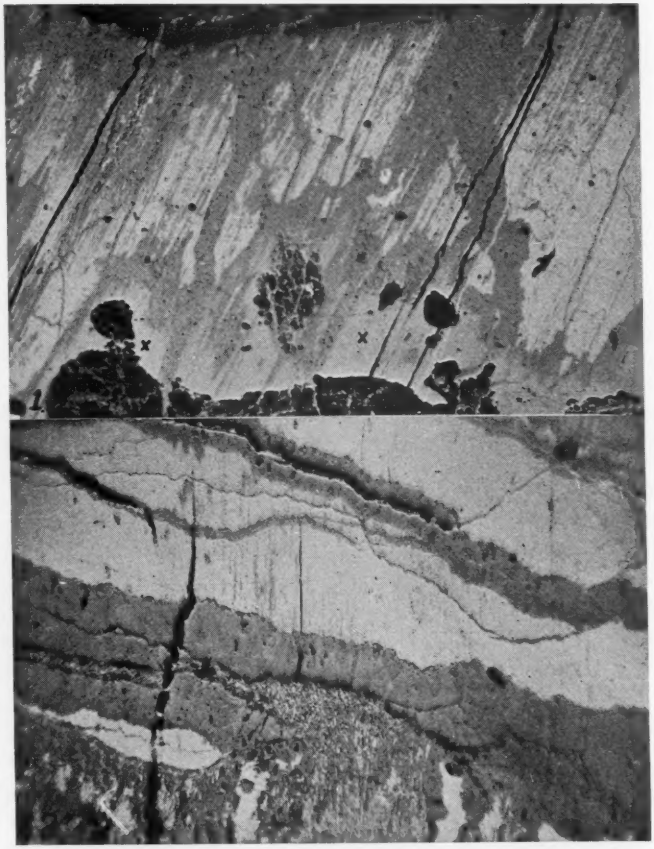

FIG. 1. Heterogeneous manganese oxides in a specimen that appeared to be homogeneous. Replacement of manganite (light gray) by hetærolite (dark gray). Unknown manganese oxide, *X*, may, also, be replaced by hetærolite. × 40.

FIG. 2. Stringer-like character of hetærolite (dark gray) in relation to manganite. × 120.

etch reactions which serve to distinguish hetærolite from hydrohetærolite, the following are recorded by the writer on the Tombstone material. It has been assumed that the material is hetærolite because of the negative test for water. The mineral associations, however, suggest that it may be hydrohetærolite.

Negative: Conc. HNO_3, KCN, $FeCl_3$, H_2SO_4.
Positive: Conc. HCl, etches instantaneously turning the mineral reddish-brown.
Conc. $SnCl_2$ etches instantaneously turning the mineral reddish-brown.
H_2O_2, effervesces.

Polianite and pyrolusite are common minerals in the ore from many of the mines. Identification is based on hardness, as it is thought they are two separate minerals. In hand specimens, the compact fine-grained manganese dioxide generally has the greater hardness and is identified as polianite. Polished sections reveal it to have a characteristic grain pattern (Fig. 3). Associated with polianite is an unknown manganese oxide containing arsenic (Fig. 4). It may belong to the hollandite group.

Pyrolusite is a soft sooty mineral easily scratched with a needle. Its occurrence as fine-grained dispersed aggregates and as elongated streaks in fibrous manganite (Fig. 5) suggest a later deposition than manganite. Other minerals associated with pyrolusite are psilomelane, various hydrous iron oxides, and cellular quartz.

Crystals with the external form of manganite, $Mn_2O_3.H_2O$, occur in parallel groups of prismatic needles and soft fibers in many druses and cavities. These crystals, however, may be pseudomorphs of pyrolusite produced by the dehydration and oxidation of manganite.

Psilomelane, H_4MnO_5, occurs as hard, compact masses, commonly intergrown with polianite and other undetermined manganese oxides and is the most abundant and widespread of the manganese minerals at Tombstone. Examination of representative specimens in polished section brings out the truly typical structures of psilomelane (Fig. 6) and shows the difficulty of

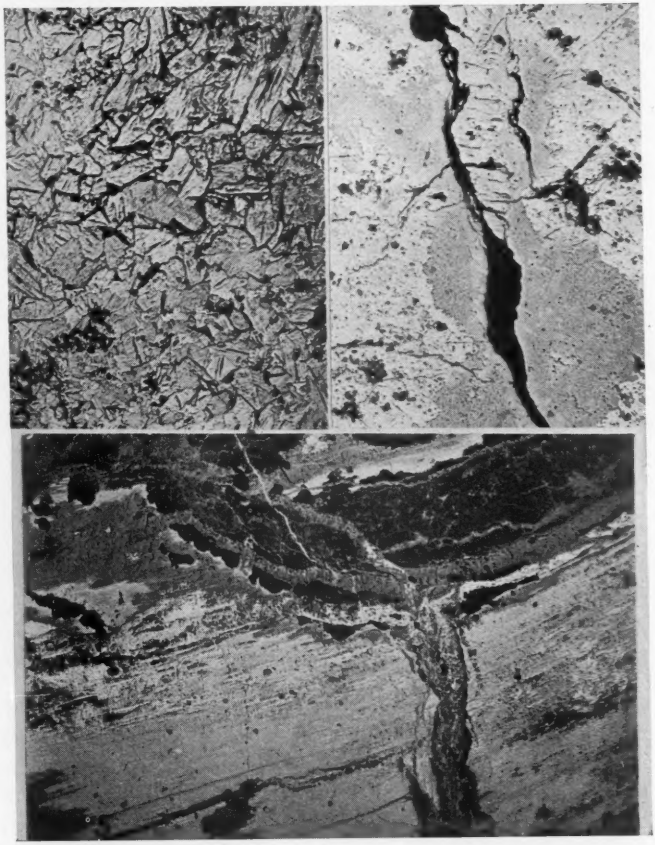

FIG. 3. Grain pattern of polianite. × 40.

FIG. 4. Polianite (white) replaced by unknown manganese oxide (gray). × 40.

FIG. 5. Manganite (light gray) replaced by fine stringers of pyrolusite (white) and cut by stringers of hetærolite (dark gray). × 75.

distinguishing it from others because of its variable reflecting power and hardness. Apparently, psilomelane was deposited as nodular and botryoidal crusts about different nuclei to form irregular concentric masses with varying degrees of hardness. Some concentric masses were fractured and the cracks later filled with a harder variety of the same mineral.

A mineral with distinct bluish tint under the microscope and commonly associated with polianite (Fig. 4) was at first determined as *hausmannite*. Since the mineral is isotropic it can not be hausmannite. Etch reactions suggested hetærolite, but microchemical tests gave arsenic instead of zinc. These characteristics may be those of a manganese arsenate, but suitable material for analysis is lacking. The mineral takes an excellent polish and is slightly softer than polianite. Etch reactions on the mineral are recorded by the writer.

Negative: Conc. HNO_3, KCN, H_2SO_4, KOH, $HgCl_2$
Positive: Conc. HCl, etches gray.
Conc. $SnCl_2$, etches gray; in oblique light the mineral appears reddish-brown.
$FeCl_3$, etches light brown.
H_2SO_4, slight etch, may be negative.
H_2O_2, effervesces vigorously; leaves a brown stain.

Manganese carbonates are represented by small quantities of reddish-brown rhodochrosite associated with oxidized alabandite and abundant quantities of manganiferous calcite known as "black calcite." There are numerous veins of coarse crystalline "black calcite" which vary from a few inches to two feet in thickness whose origin is uncertain. Some are definitely supergene in origin as they occur in caverns and "water channels." The study of "black calcite" has been limited to the zone of oxidation, through the lack of exposures, and so far as known it may change to ordinary white calcite below that zone. Thin sections of some of the coarse, cleavable "black calcite" indicate that the coloring is due to disseminated feathery and arborescent growths of a brownish to black oxide of manganese (Figs. 7 and

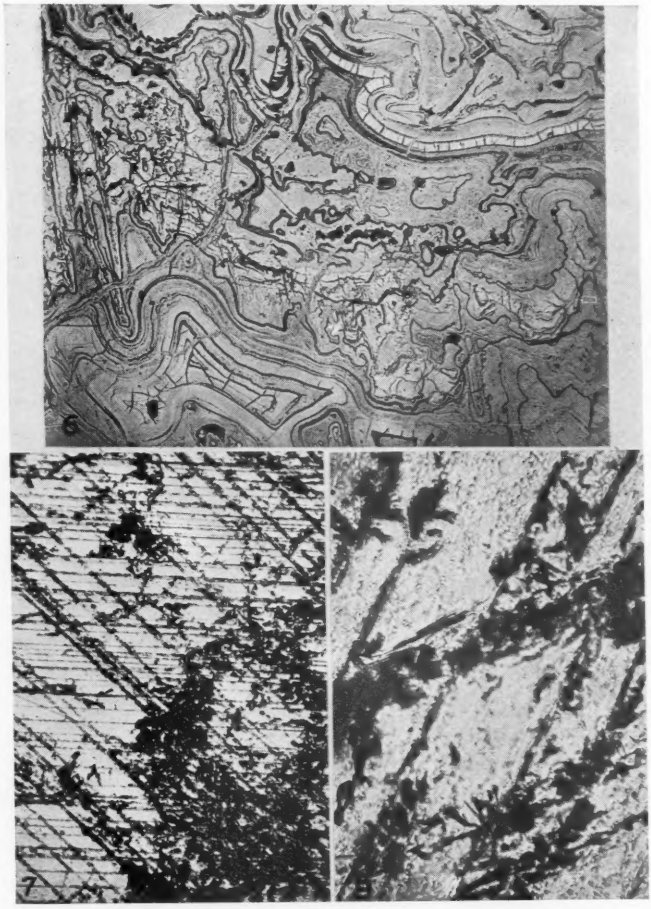

FIG. 6. Nodular and botryoidal psilomelane. Different colors probably represent layers of varying hardness. × 40.

FIG. 7. Thin section of "black calcite" showing replacement of calcite by manganese oxide along cleavage cracks. Plain light. × 24.

FIG. 8. Concentration of feathery and spherulitic brown oxide at intersection of cleavage planes. Plain light. × 320.

8) replacing the calcite along the cleavage cracks, more in one cleavage than in the other.

Samples of the typical "black calcite" dissolved in a 10 per cent solution of hydrochloric acid left a brownish-black residue when filtered. The residue effervesced and was completely dissolved by hydrogen peroxide. It probably represents some hydrated oxide of manganese. From the solution only calcium and manganese were obtained.

What is the origin of the manganese oxide in the "black calcite"? Is the manganese oxide hypogene or supergene? Hewett and Pardee [5] have considered "black calcite" from other districts as hypogene, and at least part of it may be hypogene at Tombstone. Thin sections indicate that the manganese oxide is later than the calcite, which it replaces along the cleavages. Should the "black calcite" veins below the zone of oxidation change to white calcite veins the original manganese mineral could be one of the light colored manganese oxides, manganosite, MnO or pyrochroite, $Mn(OH)_2$, which turn dark on exposure to air. These minerals are thought to be hypogene in other districts where they occur. If the black oxide had been formed from the alteration of hypogene carbonate, silicate, or sulphide, relics or other evidence of an earlier mineral would have been recognized. Positive evidence may be obtained when mining is undertaken below the zone of oxidation.

SOURCE AND ORIGIN OF THE MANGANESE OXIDES.

The source of the manganese oxides at Tombstone has received little discussion. Church [6] and Ransome [7] considered the Carboniferous limestones as the source of the manganese oxides and the pipe-like deposits as secondary depositions from these lime-

[5] Hewett, D. F., and Pardee, J. T.: Manganese in western hydrothermal ore deposits. Ore Deposits of the Western States (Lindgren volume), A. I. M. E., pp. 680–681, 1933.

[6] Church, J. A.: The Tombstone, Arizona, mining district. Trans. A. I. M. E., 33: 29, 1903.

[7] Ransome, F. L.: Bisbee and Tombstone districts, Conchise county, Arizona. U. S. Geol. Surv. Bull. 710: 119, 1920.

stones. Goodale[8] showed that the country rock exposed by cross-cuts and drifts near the ore chimneys did not contain manganese in appreciable quantities, and did not believe that the limestones were the source for the origin of the ore.

As alabandite is the only definitely established hypogene manganese mineral in the district, it is believed by the writer that the manganese oxides have been derived solely from the oxidation of alabandite and not in part from the Carboniferous limestones. Possibly, some of the oxides may have resulted from the decomposition of "black calcite." Moreover, Hewett and Rove[9] have suggested that the oxidized manganese ore bodies at Bisbee, Arizona, which are similar to those at Tombstone, were derived from the oxidation of alabandite, not only because of its presence but because the resulting deposits showed few voids, a feature not characteristic of deposits resulting from carbonates or silicates, which show abundant voids or drusy cavities. The Tombstone deposits are, likewise, free of voids. Since alabandite oxidizes much more readily and rapidly than either the silicate or carbonate and all the other sulphides, it would not leave residual relics.

Considering alabandite as the primary source of the manganese in the oxides from the Lucky Cuss mine, it is reasonable to assume that it is the source for all manganese oxides from other mines in the district. The oxidation of alabandite has been little studied in contrast to the extensive investigations of the oxidation of copper and iron sulphides. This is because of its rarity. Likewise, its rarity in certain western lode deposits may be due to its more rapid decomposition than the sulphides of any other common metal. At Tombstone, alabandite from the Lucky Cuss mine dumps has oxidized rapidly since it was mined. Unless one knows what to look for, the weathered specimens are easily overlooked.

[8] Goodale, C. W.: The occurrence and treatment of the argentiferous manganese ores of the Tombstone district, Arizona. Trans. A. I. M. E., 17: 700, 1888–89 and 18: 910, 1889–90.

[9] Hewett, D. F., and Rove, O. N.: Occurrence and relations of alabandite. ECON. GEOL., 25: 41, 1930.

What are the chemical processes involved in its oxidation and the precipitation of the manganese as the oxides? Freshly broken surfaces of a number of oxidized alabandite specimens showed unaffected pyrite grains. Hence, alabandite seems to have oxidized earlier than pyrite, possibly by the following reaction:

$$MnS + 4O = MnSO_4.$$

Polished specimens show small amounts of galena, sphalerite, tetrahedrite and chalcopyrite also, associated with alabandite. During the oxidation of this sulphide ore body, alabandite may have oxidized to manganous sulphate through the action of sulphuric acid formed by the oxidation of pyrite.

Since all sulphide ore bodies are highly acid when oxidizing, it is held by the writer that sulphate solutions played a dominant part in the solution and transportation of the manganese at Tombstone. It is also held that manganous sulphate became neutral without involving the formation of manganese bicarbonate, which, also, must become neutral before precipitation can take place. Furthermore, manganese bicarbonate in the presence of limestone would likely precipitate manganese carbonate as has been suggested by Savage.[10] It is likely that manganese carbonate can be precipitated only from a neutral or slightly alkaline solution and would not be found in an oxidizing ore body. Therefore, to quote Emmons:[11]

> As sulphuric acid tends to drive carbon dioxide out of solution, it would not be supposed that highly carbonated waters would be common in oxidizing zones of mines where the ore carried much pyrite. That small amounts of sulphuric acid and carbonates may exist in the same solution is shown, however, by several analyses.

That mine waters in limestone areas are strongly acid can be shown in the composition of mine waters of the Joplin region.[12]

> The table on page 103 gives analyses of mine waters of the Joplin district, Missouri. . . . These waters closely resemble those obtained in

10 Savage, W. S.: Solution, transportation, and precipitation of manganese. ECON. GEOL., 31: 288, 1936.

11 Emmons, W. H.: The enrichment of ore deposits. U. S. Geol. Surv. Bull. 625: 94, 1917.

12 Emmons, W. H.: *Op. cit.*, p. 102.

mines of lode ores in the Western States. They are strong sulphate solutions. . . . In view of the fact that the deposits are in calcareous rocks the acidity is noteworthy.

The lack of analyses of mine waters from the Tombstone district does not preclude the belief that they are not acid, for ettringite, a rare calcium-aluminium sulphate, was thought by Moses [13] to have been formed by the action of sulphuric acids of supergene origin upon limestone and silicate-bearing rocks.

Since the pipe-like manganese ore bodies at Tombstone consisted of alabandite with pyrite, galena, sphalerite, and sulphides of copper, exposure of the ore body to erosion and fluctuations of the water table would cause the manganese sulphide to be oxidized to manganous sulphate and the pyrite to ferrous and sulphuric acid. Sulphuric acid would act upon the other sulphides to change them to sulphates, but more readily on manganese because of its decided solubility in acid solutions. At the same time ferric sulphate solutions would form under favorable conditions. The ferric sulphate would react immediately on the calcium carbonate to form soluble calcium sulphate, carbonic acid, and ferric hydroxide. Sulphuric acid would tend to drive out any carbon dioxide that would form. Intermingling of solutions and reactions with minerals and wall rock would cause precipitation of the minerals out of solution. Examination of the old stopes has shown a definite separation of the iron and manganese minerals. In the central core of the ore bodies, the mass consisted of iron oxides associated with oxidized minerals of lead, zinc, copper, and silver with small amounts of manganese oxides. Surrounding this core there was an envelope of hard, massive manganese oxides with few other associated minerals. This separation of manganese and iron took place in the presence of limestone as the sulphates of the two metals percolated downward and laterally. Experiments [14] have shown that when ferrous sulphate and manganous sulphate are together in the presence of calcite and air,

[13] Moses, A. J.: Ettringite from Tombstone, Arizona, and a formula for ettringite. Am. Jour. Sci., 3d ser., 45: 489–492, 1893.

[14] Emmons, W. H.: The agency of manganese in the superficial alteration and secondary enrichment of gold deposits in the United States. Trans. A. I. M. E., 42: 39, 1912.

the iron is by far the more easily precipitated, whereas the manganese will remain in solution until all the iron has been precipitated. Manganese sulphate acts but little upon calcium carbonate, if protected from access of air, but is precipitated as the oxide on neutralization in the presence of both air and calcium carbonate.

Dunnington [15] was probably the first to suggest that many deposits of manganese oxides in calcite rocks owe their formation to the action of sulphates. He reached this conclusion from a series of experiments in which he subjected manganese oxides, chiefly psilomelane, to the action of ferrous sulphate and sulphuric acid in about the proportions that would form from the oxidation of pyrite. The rate of solution of a lump of compact psilomelane was equivalent to 3.78 inches in one year. If the rate of solution is so great on relatively insoluble oxide, what might it be on the relatively soluble manganese sulphide? So far as known, there has been no laboratory experiment on the oxidation of manganese sulphide by any agents that approach those found in an ore body undergoing oxidation.

Thus, when ore bodies or rocks containing manganese undergo weathering, the manganese is taken into solution by the solvent action of waters containing sulphuric or carbonic acid. The manganese at Tombstone went into solution as the sulphate, because sulphides are present to form the sulphuric acid or sulphates. The sulphates readily hydrolyze and form acid solutions in water. The great depth to which manganese oxides have been found suggests that the manganese was carried downward as an acid, for the sulphates are more stable in acid solutions than in neutral or alkaline. Thus on neutralization of a manganese sulphate solution through the action of oxygen in the presence of calcite, the oxides will be precipitated. Suggested reactions are as follows:

$$MnSO_4 + 2H_2O = Mn(OH)_2 + H_2SO_4.$$

[15] Dunnington, F. P.: On the formation of deposits of oxides of manganese. Am. Jour. Sci., 3d ser., 36: 175–178, 1888.

Some of the manganous hydroxide is oxidized by the air to manganous acid,

$$Mn(OH)_2 + O = H_2MnO_3 \text{ or } MnO_2 + H_2O,$$

which on coming in contact with manganous hydroxide immediately forms a salt with it.

$$H_2MnO_3 + Mn(OH)_2 = Mn_2O_3 + H_2O.$$

ACKNOWLEDGMENTS.

This paper represents a portion of a dissertation on the mineralogy of the Tombstone mining district, submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy at the University of Arizona. The writer gratefully acknowledges the guidance and criticisms of Dr. B. S. Butler in the preparation of the manuscript and to Dr. M. N. Short for aid on the polished sections of manganese minerals. To Dr. D. F. Hewett, Dr. W. T. Schaller, and Dr. R. C. Wells of the U. S. Geological Survey the writer is especially grateful for their criticisms and suggestions.

BOISE, IDAHO,
May 4, 1939.

NOTES ON THE USES OF METHYL METHACRYLATE "LUCITE" IN A GEOLOGICAL LABORATORY.

JAMES FORBES BELL.

ABSTRACT.

Methyl methacrylate "Lucite" is a colorless transparent plastic which has been found useful for mounting and impregnating specimens in a geological laboratory. Various applications and the technique of handling this material are described.

THE polymerization of monomeric methyl methacrylate to form a clear, colorless, hard, tough solid has been found useful in handling many geological and mineralogical specimens. This material has been used for several years in mounting and impregnating textiles, woods, paper and various biological and botanical specimens. It is thought that the properties and methods of handling this material should be brought to the attention of geologists.

The writer is indebted to Cortland S. Pearsall of the Metropolitan District Water Supply Commission, Boston, who introduced him to the possibilities of using methyl methacrylate and who made the first geological specimen mounts with this material in the laboratories at the Massachusetts Institute of Technology.

Tables I and II [1] show the physical properties of liquid (mono-

TABLE I.

PROPERTIES OF MONOMERIC METHYL METHACRYLATE.

Sp. gr. 60°/60° F. (15.6°/15.6° C.)	0.9497
Refractive index $n\frac{15.6}{D}$	1.4168
B.p., ° C.:	
760 mm	100.3
200 mm	61
1000 mm	46
M.p., ° C.	−48
Relative Viscosity, 22° C.	0.588
Latent heat of vaporization, cal./gram:	
765 mm	77
200 mm	88
Sp. heat, cal./gram/° C.	0.49
Solubility: Soluble in typical organic solvents; insoluble in water and formamide; slightly soluble in glycerol and ethylene glycol.	

[1] E. I. duPont de Nemours Co. Contribution "Methacrylate resins." Ind. Eng. Chem., 28: 1160–1163, 1936.

TABLE II.

PROPERTIES OF UNPLASTICIZED POLYMERIC METHYL METHACRYLATE.

General:	
Density, 25° C.	1.19–1.20
Hardness, Brinell scale	25–28
Softening temp., ° C.	80–125
Shrinkage of molded resin in./in.	0.003–0.005
Water absorption, %	About 0.5 or less
Mechanical:	
Tensile strength, lb./sq. in.	8,000–11,000
Impact strength (A.S.T.M. notched), ft./lb.	0.23–0.27
Modulus of elasticity, lb./sq. in.	$2.3–3.0 \times 10^5$
Fiber stress, lb./sq. in.	13,000–18,000
Thermal:	
Thermal conductivity, B.t.u./sq. ft./hr./° F./in.	1.25
Coefficient at linear expansion	$8.2–9.5 \times 10^{-5}$
Optical:	
Refractive index	1.482–1.521
Light transmission	$95\%^{125}$
Ultraviolet transmission (0.01 in. film), Å	To 2500
Light stability	Excellent
Internal reflectability	Good
Electrical:	
Volume resistivity, ohms/c.c.	$2.0–3.0 \times 10^{13}$
Dielectric constant (60 cycles):	
25° C.	3.3–4.5
100° C.	5.0–6.0
Power factor (60 cycles), %:	
25° C.	6.5–8.0
100° C.	1.0–4.0
Dielectric strength (in oil at 100° C.):	
Insulation thickness, in.	Dielectric strength, volts/mil.
0.054	741
0.063	687
0.092	615
0.245	347
Arc resistance	Does not track
Inflammability:	Slow burning

Solubility: Soluble in esters, ketones, aromatic hydrocarbons, chlorinated hydrocarbons, anhydrous organic acids. Insoluble in water, aliphatic alcohols, lower aliphatic ethers, aliphatic hydrocarbons, vegetable oils, glycols, carbon tetrachloride, formamide, phosphoric acid (70%), hydrochloric acid (30%), sulphuric acid (60%), aqua ammonia, sodium hydroxide (30%).

meric) and solid (polymeric) methyl methacrylate. The low viscosity of the liquid makes it a very good impregnating agent. The transparency, index of refraction and strength of the solid make it a very good mounting medium. Since the polymerization of the liquid to make the solid can take place in a reasonably short time at atmospheric pressure and at temperatures as low as 40° C., this material is especially adaptable to impregnation and preservation of fragile and friable specimens. The toughness of the

polymer makes the liquid an ideal material for impregnating and mounting specimens that are to be thin-sectioned. Since the polymer is not attacked by most strong acids and alkalies, it is a good material to use as a transparent coating for glassware in which etching may be carried on. It is also possible to embed acid soluble objects in this resin, subsequently dissolve the embedded object and have a perfect mould of the specimen. For exhibition purposes small specimens may be magnified by mounting them in the center of a cylinder or sphere of the resin.

At present the writer is developing a technique for using this material to embed crystals that are to be deformed. By this method it is possible to observe the deformation of crystals under fairly high confining pressures.

PROCEDURE FOR IMPREGNATING AND MOUNTING SPECIMENS.

The monomeric methyl methacrylate usually contains a trace of inhibitor when it is purchased.[2] This inhibitor prevents polymerization from taking place at room temperature. The liquid with the inhibitor is colorless and highly volatile. The vapor is toxic so that precautions should be taken to work with the material under a hood as much as possible. This liquid is placed in a separatory funnel (Fig. 1) and an equal volume of a 2% potassium hydroxide solution is added. After vigorous shaking the potassium hydroxide with the inhibitor will settle to the bottom of the funnel as a dark brown liquid. This is removed and the operation repeated until the alkali layer in the funnel shows no trace of color. The monomer without the inhibitor is a colorless liquid. This is washed two or three times with water, allowing the water to settle to the bottom of the funnel after each shaking. After shaking with water the monomer has a cloudy appearance which is due to small water bubbles which haven't settled. In order to clear fully, the monomer must stand for several hours. After the last washing the process of clearing can be quickened by adding calcium chloride in the funnel.

[2] E. I. duPont de Nemours Co., Ammonia Dept., Experimental Station, Wilmington, Delaware (cost about $8.00 per gallon in 5 gallon lots).

When the monomer is dry, this can be filtered off. The monomer is now ready to harden and this procedure can be varied a great deal. Hibben[3] has given a good description of his technique.

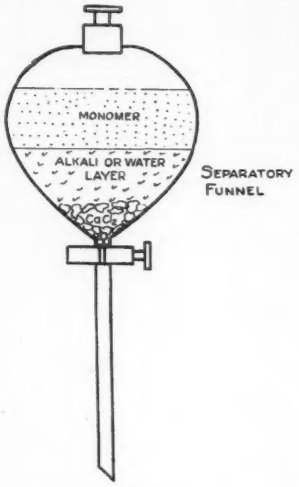

FIG. 1.

Knight[4] has pointed out that the U. S. Dept. of Agriculture is carrying on a large program of research along this line but, as yet, the results of their experiments are not available.[5] The writer will outline the procedure which he has been successfully using. Heat, light and free oxygen are catalysts for the polymerization which is an exothermic chain reaction. The greatest difficulty is encountered in trying to prevent bubbles from forming during polymerization. If the reaction takes place too rapidly the solid product has the appearance of a solid soap lather because of the many bubbles.

[3] Hibben, J. H.: The preservation of biological specimens by means of transparent plastics. Science, 86: 247–248, 1937.

[4] Knight, H. G.: The preservation of biological specimens by means of transparent plastics. Science, 86: 333–334, 1937.

[5] Personal communication from Senior Biochemist Dr. Charles E. Sando, March 3, 1939.

Benzoyl peroxide may be added to the uninhibited monomer to speed up the polymerization. A solution of .04 gram of benzoyl peroxide per 100 c.c. of the monomer has been found satisfactory for the procedure to be described. After dissolving the benzoyl peroxide in the monomer there are two procedures that may be followed, depending upon the type of specimen that is being treated.

If the specimen is a sand or other porous material it should be placed in a container and the catalyzed monomer poured over it. Enough excess monomer should be present to allow a 20 per cent volume decrease upon hardening and also some loss due to evaporation. The specimen may then be put in a partial vacuum until all air bubbles have been drawn off. The vacuum produced by an ordinary aspirator pump is generally sufficient. The container is then placed in a water bath in an oven at a

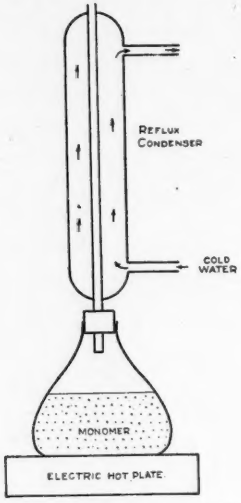

FIG. 2.

temperature of about 40–45° C. and allowed to stand until the monomer hardens. The hardening will take from four to five days.

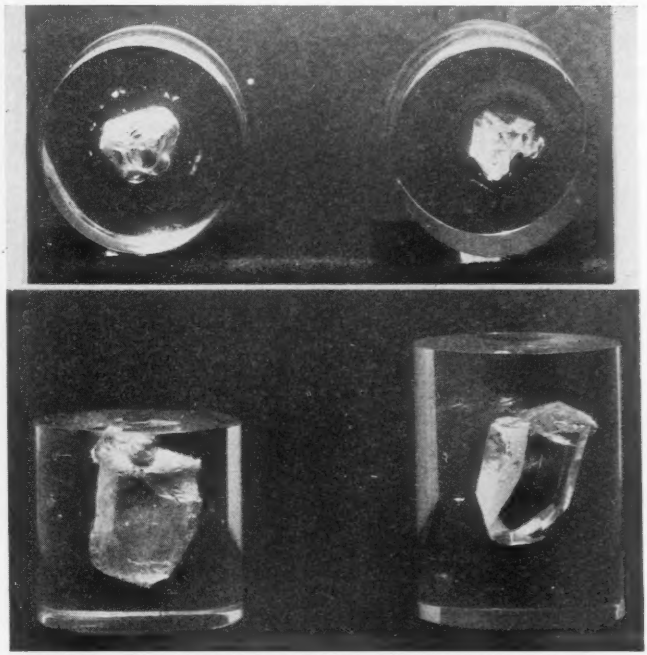

FIG. 3. End and side views of two calcite crystals mounted in cylinders of methyl methacrylate. The crystal on the right is undeformed. The crystal on the left has been deformed. The magnification due to the mount can be seen by comparing the end and side views.

If the specimen is nonporous, a day or so of hardening time can be saved by thickening the monomer before it is poured around the specimen. If only a small amount of monomer is to be thickened it can be boiled in a test tube over an electric hot plate. If the tube is long enough, there will be enough condensation at the top to prevent any great loss of the vapor. If larger amounts are to be thickened, the boiling should be carried out under a reflux condenser (Fig. 2). If the monomer boils too violently the heat source should be removed until the

bubbling has stopped. For most solid specimens the monomer can be boiled in this way until it reaches a heavy syrup-like state, which can be judged from the speed with which the bubbles rise. After heating, precaution should be taken to chill the thickened monomer for several minutes in a cold water bath to stop nearly all the polymerization; otherwise the exothermic reaction will

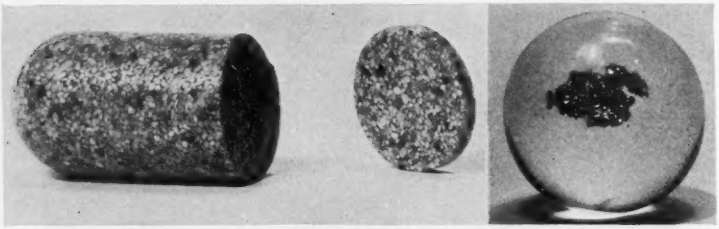

FIG. 4. Left, loose sand impregnated with methyl methacrylate for thin sectioning.

Right, cluster of gold crystals mounted in a sphere of methyl methacrylate. The specimen is magnified about three times by the mount.

go on and the monomer will solidify in a mass of bubbles within an hour or two. This thickened monomer can then be poured over the specimen and placed in a water bath in an oven at a temperature of about 40–45° C. The hardening will take from two to three days. Perfectly clear blocks 1½ inches in diameter and 2 inches long have been made in this manner.

The vessel containing the monomer should be sealed while it is in the oven. If rubber stoppers are used they should be covered with tin foil because the monomeric methyl methacrylate attacks rubber, causing it to swell. In the work that has been carried on here, glass containers have been used as molds and they can easily be broken away from the finished mount. It is important that the monomer be kept in a water bath while it is in the oven. The water has a high enough specific heat to carry away most of the excess heat generated by the exothermic reaction thereby mitigating the chances of forming bubbles. It should always be remembered that the liquid and the vapor of

the monomer are toxic and inflammable and suitable precautions should always be taken. It is also necessary that all the vessels that are used in handling the monomer should be perfectly dry, otherwise the monomer will become cloudy when it hardens.

The polymerized methyl methacrylate can be machined very easily and mounts can easily be cut to any desired shape.[6] After fine sanding, it can be polished in a very few minutes by using a velveteen lap lubricated with liquid soap.

DEPT. OF GEOLOGY,
MASS. INST. OF TECHNOLOGY,
CAMBRIDGE, MASS.,
June 10, 1939.

[6] Lockrey, A. J.: Plastics in the School and Home Workshop. Governor Publishing Corp., N. Y. City, 1937.

ASBESTOS AND CHROMITE DEPOSITS OF WYOMING.

R. H. BECKWITH.

ABSTRACT.

Serpentine occurs as lenses from 50 feet to several miles across in the pre-Cambrian rocks forming the cores of the anticlinal mountain ranges of central and northwestern Wyoming. The serpentine is younger than metamorphosed sediments, is cut by metadiabase dikes, and both are cut by granite and pegmatites.

Chrysotile occurs in the serpentine both as cross fiber and slip fiber in veins elongated with the lens. Cross fiber up to 1½ inches long was found; most of it is short. A small tonnage has been produced from three deposits.

Microscopic examination of brittle chrysotile shows extensive replacement by quartz. Harsh chrysotile shows fine-grained quartz in rods or veinlets parallel to fiber length and in cross veinlets. Nearby pegmatites could have furnished the silica. The opinion is expressed that brittleness and harshness in chrysotile from the serpentine type of deposit is the result of introduction of silica with or without chemical reaction to form talc.

The chromite of Casper Mountain occurs disseminated, and in bands or lenses in tremolite-chlorite-talc schist, originally an ultrabasic rock. The best ore would require concentration to meet market requirements. Some laboratory concentrates contain sufficient Cr_2O_3 for the manufacture of ferrochrome; others contain an excessive amount of iron.

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INTRODUCTION.

CHRYSOTILE asbestos and chromite have been reported from various localities in Wyoming and attempts at commercial production have been made, particularly between 1905 and 1921. Detailed geologic information on the deposits has not been available. Field examination of the reported occurrences was undertaken by the Geological Survey of Wyoming, and the writer spent two months in the field during the summers of 1934 and 1935. Plane table maps of five deposits and the surrounding territory were made and four other deposits were examined. The mapping of the largest area, Casper Mountain, was carried out on a scale of 1 inch = 1,000 feet; for smaller areas scales of 500 and 300 feet to the inch were used.

All of the deposits have certain features in common. The host rock is serpentine, or a derivative of serpentine. There are younger granites in the immediate vicinity. The deposits are of pre-Cambrian age. They occur only a few hundred feet or less stratigraphically below the base of the Cambrian sediments. The probable reason for this is that pre-Cambrian rocks now close to the Cambrian beds have been protected from erosion until comparatively recent time but, in places where the pre-Cambrian rocks were exposed early in the Laramide folding, the metamorphic rocks of the roof have been extensively removed, exposing large areas of the subjacent granites. All of the deposits except those on Casper Mountain are many miles from a railroad and are not easily accessible.

The writer wishes to thank Dr. W. D. Johnston, Jr., of the United States Geological Survey for reading and criticism of the manuscript, Mr. H. F. Eppson of the staff of the Agricultural Experiment Station of the University of Wyoming for analyses of samples of chromite ore, and R. C. Shoemaker and H. H. Olinger for their able assistance in the field.

BROWN BEAR ASBESTOS DEPOSIT.

The deposit (Fig. 1) is near the head of Berry Creek approximately a mile east of the watershed of the Teton Range and 7 miles south of Yellowstone Park. The area has not been sur-

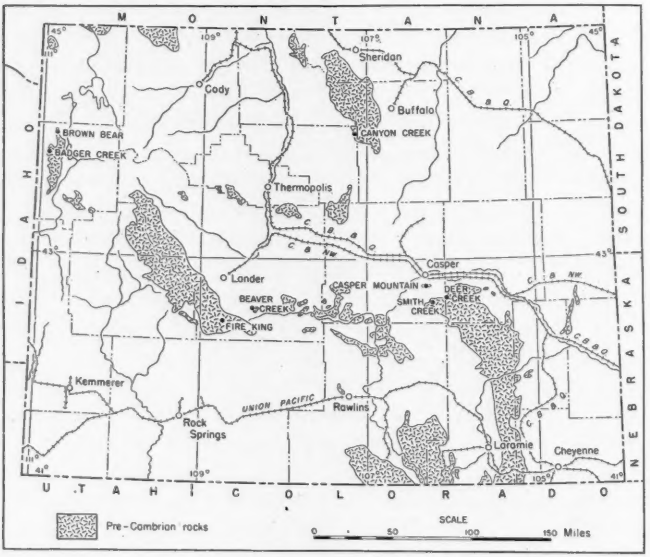


FIG. 1. Index map of Wyoming.

veyed but, according to the U. S. Forest Service map of the Teton National Forest, the claims would fall in sec. 19 or 20, T. 47 N., R. 116 W. The nearest rail point is Lamont Siding, Idaho, 25 miles to the west.

The west flank of the range consists of Paleozoic limestones and shales, and Tertiary eruptives. A few thousand feet east of the crest of the range, Berry Creek has cut through the basal Cambrian quartzite into granite, granite-gneiss, and pegmatites. A mile east of the watershed and a few hundred feet south of the creek a lens-shaped body of massive greenish-black rock is exposed in the wall of the valley. Under the microscope it consists

almost entirely of chlorite, but the disposition of areas of finely divided magnetite suggests that seen in massive serpentine. The rock was probably originally an olivine-bearing ultrabasic rock and the body a dike, or a sill, which was folded during the time of granite intrusion. The mass strikes north and stands vertically, and reaches a maximum width of 50 feet. Near the middle, the east contact parallels the banding of granite gneiss, and the west contact is bounded by a zone of talc schist 20 feet wide, which grades westward into an injection gneiss. Southward the outcrop narrows, the number of granite dikelets penetrating the ultrabasic rock increases, and the body grades into an injection gneiss. The exposed length is approximately 400 feet.

A trench near the middle of the mass exposes vertical faces of the ultrabasic rock 20 feet high, and displays numerous fractures with slickensided walls. Greenish-yellow slip-fiber chrysotile and gray coarse slip-fiber amphibole occur along some of the fractures, predominantly those parallel to the lateral contacts. Most of the veinlets are less than ¼ inch wide. In the 50 feet of trench there are two veins varying from 6 inches to a foot in width containing both varieties in different places. Both of the larger veins have been invaded by granite-pegmatite, and much of the chrysotile has been partially or completely replaced by coarse-grained quartz. The unaltered chrysotile fiber is fine and pliable. Its length varies up to two inches, but most of it is less than one inch long. Much of the fiber is broken by cross fractures. The best exposures, those along the trench, indicate that the rock as a whole contains less than 5 per cent of chrysotile. The dumps of several short caved tunnels give no indication of a higher percentage.

It is reported [1] that the property was acquired in 1917 by the American Asbestos Milling & Mining Co., of Idaho Falls, Idaho. In 1920 thirteen miles of road had been built and the property was being developed. In 1921 it was said that the property required a mill for successful exploitation and the company had not yet reached this stage of development. At the time of the writer's visit in 1934 the property had been abandoned for some years.

[1] Sampson, Edward: U. S. Geol. Surv., Mineral Resources U. S., 1920, Part II—Nonmetals, p. 317. Sampson, Edward: U. S. Geol. Surv., Mineral Resources U. S., 1921, Part II—Nonmetals, pp. 139–140.

BADGER CREEK DEPOSIT.

A reported occurrence of asbestos in sec. 5, T. 6 N., R. 117 W., on the west side of the Teton Range proved to be a small deposit of massive soapstone and fibrous talc in olivine diabase, which is cut by granites and quartz stringers.

FIRE KING ASBESTOS DEPOSIT.

The deposit is situated in sec. 26, T. 30 N., R. 100 W., in the northern part of the Atlantic gold district near the crest of the southeast part of the Wind River Range at an elevation of about 8,000 feet. It is 29 miles from Lander (Fig. 1).

The geology of the Atlantic gold district is well known from the work of Spencer,[2] who visited the Fire King group of claims in 1914 and describes other serpentine masses in the region. A brief description of the deposit is given by Diller.[3]

Along the southeast side of the serpentine bodies (Fig. 2) is a bed of pink quartzite, up to 50 feet thick, that stands vertically and strikes parallel to the serpentine contact. To the southwest the quartzite thins and grades into sericite schist. Southeast of the quartzite are alternating sericite and magnetite schists that strike generally parallel to the serpentine contact and dip steeply southeast. In the area of outcrop of the schists there are black bands many feet across. These grade across the strike into schists showing alternating bands of black and light gray material from 1/16 inch to several inches thick. The intimately banded schist grades into light gray sericite schist of uniform color. Thin sections of the black schist (Fig. 5) show that the dark bands consist principally of magnetite, but contain small amounts of quartz and green hornblende, alternating with lighter bands consisting predominantly of quartz and hornblende with a few grains of magnetite. A thin section of sericite schist shows abundant quartz, sericite, and a few grains of magnetite. The banded character of the rocks, the gradations of magnetite schist

[2] Spencer, A. C.: Atlantic gold district and the North Laramie Mountains. U. S. Geol. Surv., Bull. 626, 1916.

[3] Diller, J. S.: U. S. Geol. Surv., Mineral Resources U. S., 1917, Part II—Nonmetals, p. 201.

into sericite schist and sericite schist into quartzite, and the mineralogical composition indicate that the schists and quartzites were originally argillaceous sandstones, sandstones, and ferrugi-

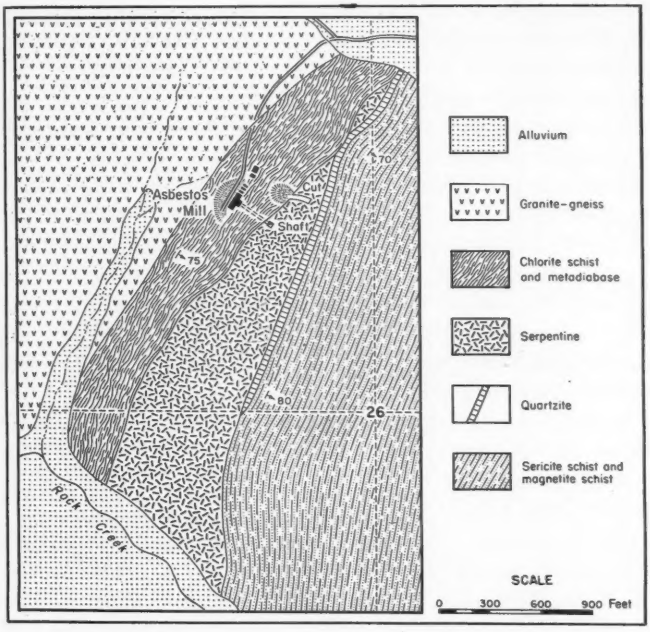


FIG. 2. Geologic map of the vicinity of the Fire King asbestos deposit.

nous siliceous sediments. Within the succession of sericite and magnetite schists there are accordant tabular bodies of metadiabase up to 100 feet thick.

Spencer [4] discusses the possibility of use of the magnetite schists for iron ore and shows that chip samples of 5 to 7 pounds across the ledges at intervals of about 2 feet for distances from 150 to 250 feet contain from 37 to 42 per cent of iron. His samples were unselected and he states there may be bodies of schist con-

[4] *Op. cit.*, pp. 17–18.

taining more than 50 per cent of iron, which are large enough to be separately mined.

The two masses of serpentine form a ridge standing several hundred feet above the floor of Rock Creek. The smaller is 350 feet long and 80 feet wide. The larger has a maximum width of 700 feet, and is exposed for a length of 2,500 feet. It apparently wedges out to the south, as it is not seen beyond Rock Creek. The serpentine is generally dark green to black in color and massive, except where it has been converted to a talcose schist. A thin section of the black massive material shows that it consists almost entirely of serpentine. Magnetite occurs as a fine powder dispersed through the rock, in irregular rounded masses, and in elongated streaks. There are a few irregular patches of carbonate material replacing the serpentine. Although there are no remnants of primary minerals or replacement structures that would serve to identify them, it is probable that the present serpentine bodies were originally intrusives of an ultrabasic rock such as peridotite or dunite.

Northwest of the serpentine is a belt of lenticular chlorite schists and metadiabases up to 400 feet wide. The schistosity generally parallels the northwest contact of the serpentine. The chlorite schist contains, in addition to chlorite, remnants of brown basaltic hornblende, and a fine aggregate of chlorite intergrown with what is probably quartz. A thin section of a metadiabase shows green hornblende derived from a pyroxene, labradorite, and chlorite occurring along fractures in the hornblende. The evidence indicates that the chlorite schists and metadiabases were originally basalt flows and diabase sills.

All of the rocks described are cut by granites. Dikes and dikelets of granite are particularly abundant in the belt of the chlorite schist and metadiabase. To the northwest, dikelets penetrating between the leaves of the schist increase in number, and there is a transition from rocks consisting predominantly of basic schistose material to granite-gneisses containing uninjected remnants of metadiabase.

Certain conclusions as to the pre-Cambrian history can be

drawn. The granites cut all other rocks and are the youngest. The ultrabasic rock now represented by the serpentine is probably the next older, as no diabase dikes were observed cutting it. The lenticular shape of the serpentine bodies and their accordant relation to the quartzite and to the chlorite schists and metadiabases suggest that the serpentine was originally an ultrabasic sill. It is possible, however, that the basic and ultrabasic rocks were both formed during the same period of igneous activity and that the sill was intruded in the later part of the period. Assuming that the area was affected by only one period of basic igneous activity, an assumption contrary to which Spencer gives no evidence after study of a much larger area, the sericite schists, magnetite schists, and quartzites are the oldest rocks, as they act as host for accordant sill-like bodies of metadiabase.

Chrysotile occurs in the small serpentine lens, and in the northern part of the large one in a zone some 150 feet wide and 900 feet long lying along the northwest contact. The serpentine is here cut by roughly parallel veinlets of cross fiber lying generally parallel to the serpentine contact. The serpentine bordering each veinlet is altered to a light-green, massive variety, whose width is generally proportional to the width of the chrysotile veinlet. Where veinlets are closely spaced all of the intervening serpentine is altered.

In the smaller serpentine lens, shallow pits and trenches show fiber less than ¼ inch in length. The veinlets are mostly spaced some inches apart. Judging from the trench and surface exposures, it is doubtful that any considerable tonnage of rock containing 5 per cent of this short fiber could be obtained. In the large serpentine body the best surface showing is in the cut indicated on Fig. 2. This cut is 125 feet long, 25 feet wide, and 20 feet deep at the east end. In the north wall, 20 feet from the east end, is a vein 6 inches to one foot wide, which branches upward into two narrower veins. There is little massive serpentine in the vein, but the cross fiber is cut by fractures parallel to the walls, so that the length of a large part of the fiber is less than ½ inch. On the south side of the cut the vein shows approximately

the same width and character of fiber, but does not branch. It is exposed in a tunnel extending south from the bottom of the cut and in a trench parallel to the strike for a distance of 30 feet. A trench 75 feet southwest along the strike encountered no fiber. The proved length of the vein is 50 feet. In the walls of the remainder of the cut there are a few veinlets of cross fiber less than ¼ inch long and spaced some inches or feet apart. It is unlikely that this material could be profitably mined.

In the walls of the shaft (Fig. 2) is a vein 6 inches to a foot wide dipping steeply southeast. The lower part of the shaft and the mouth of the tunnel leading to the mill were caved in at the time of examination. James Carpenter of Atlantic City provided the following information: The shaft is 72 feet deep. From the bottom of the shaft a drift extends 400 feet northeast. For 300 feet the asbestos has been stoped out nearly to the surface and has been worked out for 12 feet below the level of the tunnel to the mill. From the bottom of the shaft a drift extends 50 feet southwest along the strike and another extends 150 feet southeast to the southeast contact of the serpentine.

Southwest of the shaft for a distance of 300 feet there are shallow pits and trenches, some of which show a few widely spaced veinlets of short fiber. Several trenches near the south end of the body disclosed barren rock. Since most of the exposure of the serpentine is bare rock, it is improbable that prospecting has missed any considerable amounts of chrysotile at or near the surface.

The chrysotile is light greenish-yellow in color. Fiber up to 1½ inches long was collected by the writer. The material in place in the large cut is mostly less than ½ inch long and crude material left in the mill is of this length or shorter. The fiber is fine and flexible and has been spun into yarn of good quality.

The property was prospected in 1914 by William Brice of Lander.[5] In 1917 it had passed into the hands of the American Fireproofing & Mining Co. of Denver.[6] In 1918 or 1919 several

[5] Spencer, A. C.: *Op. cit.*, p. 19.

[6] Diller, J. S.: U. S. Geol. Surv. Mineral Resources U. S., 1917, Part II—Nonmetals, p. 201.

cars of No. 1 and No. 2 crude fiber were shipped from Lander. The mill was built in 1919[7] and was operated for a short time. No production has been reported since 1920.

BEAVER CREEK ASBESTOS DEPOSIT.

The deposit (Fig. 3) is located in the southern border of the Wind River Basin in sec. 19, T. 30 N., R. 96 W., some 38 miles from Lander, and 5 miles south of Beaver Hill on the highway to Rawlins.

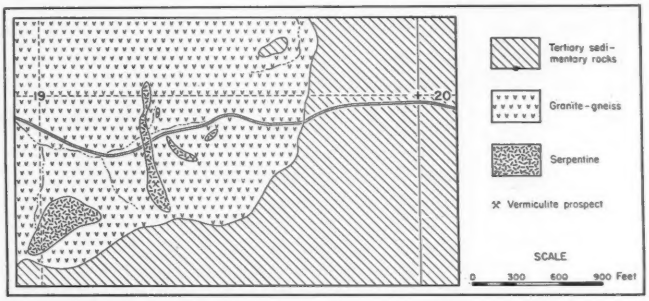


FIG. 3. Geologic map of the vicinity of the Beaver Creek asbestos deposit.

To the south and east of the claims is a gently rolling upland underlain by buff and white stratified volcanic ashes, which are probably the southern continuation of the beds of the White River group in the upper part of Beaver Hill. The Tertiary sediments in the mapped area are only a few feet thick, and in places contain boulders of pre-Cambrian granites and metamorphics up to a foot in diameter. The pre-Cambrian rocks are predominantly granite-gneisses and pegmatites. Within the granites are five lenticular bodies of massive serpentine, which are apparently roof-pendants or uninjected remnants left after stoping and injection by granitic magma of a variety of schists including some of ultrabasic composition. A few blocks and tabular remnants of metadiabase are also enclosed in the granites.

[7] Diller, J. S.: U. S. Geol. Surv., Mineral Resources U. S., 1919, Part II—Nonmetals, p. 304.

The serpentine masses are well exposed, and are readily detected by the age. The western lens, which is 600 feet long and 250 feet wide, has been irregularly fractured in places, but the fractures are filled with massive serpentine. The central lens, which is 900 feet long and has a maximum width of 130 feet, is generally similar. In the gulch 50 feet north of the road, however, a zone of steeply dipping cross-fiber chrysotile veinlets striking generally parallel to the lateral contacts of the serpentine mass has been exposed by shallow trenching. The longest fiber seen by the writer was ¼ inch in length. Fred Abernathy, the claim owner, reports finding fiber up to 1¼ inches long. Although the fiber is fine and flexible, the shortness of most of it and the small amount shown in the trenches indicate that successful commercial production is unlikely. No asbestos was seen in the three smallest lenses.

In two places in the southern part of the central lens the serpentine is cut by pegmatite dikes along the borders of which vermiculite has developed. Prospect pits twelve feet deep show that the vermiculite extends several feet from the dikes and may extend farther. Surface cover prevented observations on the lateral extent of the vermiculite zones parallel to strike of the dikes.

CASPER MOUNTAIN.

Casper Mountain is the westernmost part of the Laramie Range (Fig. 1) in which pre-Cambrian rocks are exposed. The top of the mountain in T. 32 N., R. 79 W., (Fig. 4) is a rolling upland at elevations of 7,500 to 8,000 feet dissected by a few shallow valleys. The area can be easily reached by a good road, 8 miles out from Casper.

Casper Mountain was visited by Diller, who gives a brief description of the general geology, asbestos, and chromite deposits of the region including Smith Creek and Deer Creek.[8]

[8] Diller, J. S.: Types, modes of occurrence, and important deposits of asbestos in the United States. U. S. Geol. Surv. Bull. 470: 512–516, 1911, and Occurrence of asbestos in Wyoming. Min. Sci., 63: 447–448, 1911.

General Geology.

Casper Mountain is a strongly unsymmetric westward-trending anticline, of Paleozoic beds, with a gently dipping south flank,

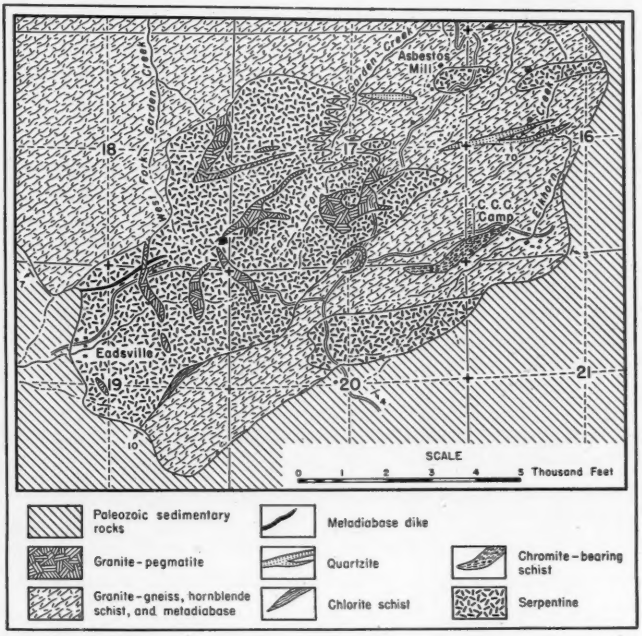


FIG. 4. Geologic map of part of Casper Mountain.

and a steeply dipping north flank. At the north base of the mountain pre-Cambrian and Paleozoic rocks lie on Upper Cretaceous beds along a southward-dipping thrust fault. In mapping the area no attempt was made to differentiate the Paleozoic rocks, but Pennsylvanian, Mississippian Madison limestone, and Cambrian Deadwood sandstone formations are present. In the NE¼ sec. 20 and in sec. 19 serpentine has been partially replaced by fine-grained silica showing colloform structures and has been oxidized to a reddish color to a depth of at least 20 feet below

the base of the Deadwood. Near the abandoned mining camp of Eadsville, prospect pits in the red weathered zone show green copper stain.

Several square miles are underlain by serpentine. Most of the material is black on fresh fracture and weathers light gray, but near pegmatites may be yellowish-green in color. A thin section of a specimen from the small mass in secs. 16 and 17 shows unaltered remnants of olivine, indicating that the serpentine was originally an ultrabasic intrusive. In a number of places, particularly around the edges of the masses, the serpentine has been converted to schist. The zone of chlorite schist in E½ sec. 19 along the contact with granite-gneiss is a schistose phase of the serpentine. Tremolite was developed first and then was partially replaced by chlorite. A specimen from the west end of the serpentine body in secs. 20 and 21 consists predominantly of nonfibrous anthophyllite. Evidence is presented below indicating that the chromite-bearing schist in secs. 16, 17 and 20 was originally an ultrabasic rock.

The serpentine is cut by metadiabase dikes. One from sec. 19 contains labradorite laths surrounded by a yellowish-brown pyroxene, which has been partially converted to green amphibole. Others have been so strongly metamorphosed that the original diabasic structure is no longer visible. Most of the dikes are too small to map; one up to 50 feet in width and half a mile long is shown on the map in secs. 18 and 19.

There are numerous remnants of hornblende schist and amphibolite within the granite-gneisses. One from northeast of the asbestos mill shows basic andesine and brown biotite; the rock was originally an andesite. It is probable that the original material now represented by the metadiabases and hornblende schists was formed during a single period of igneous activity.

The quartzites are intruded by granitic dikes, but were not observed to be cut by metadiabase dikes; the age of the quartzite, therefore, is not clear. Remnants of hornblende schist and metadiabase parallel the curved, quartzite outcrop. Lenses of green amphibolitic material up to several inches thick occur within the

quartzite, but none could be found crossing the bedding. This material consists mostly of green pleochroic hornblende.

The granites are the youngest pre-Cambrian rocks; it is probable that their gneissic structure is inherited from schists. They have so obscured relations in the older rocks that the original form of the serpentine bodies and their structural relations to the basic rocks, quartzites and any previously existing host rocks are largely matters of conjecture.

The serpentine is cut by numerous pegmatite dikes up to several hundred feet across, containing microcline, quartz and some schorl variety of tourmaline. They merit further investigation as a possible source of commercial feldspar.

Asbestos.

The areas of asbestos-bearing serpentine are confined to sec. 16 and the E½ sec. 17. Trenches and pits in the serpentine to the south and west show no chrysotile. The lens crossed by Elkhorn Creek in sec. 16 is locally traversed by steeply dipping veinlets of cross fiber. Surface workings in the hillside indicate that most of the fiber is less than ⅜ inch in length. Judging from the surface exposures and prospects it is not likely that there are extensive areas in which the rock contains more than 5 per cent of fiber.

A large part of the asbestos mined has come from a lens 1,400 feet long and 500 feet wide southeast of the mill. Several shallow pits east of the road show small amounts of fiber under ¼ inch in length. Near the center of the lens, west and north of the road, a pit 100 feet across and 40 feet deep exposes a tabular zone of cross fiber up to 18 inches in width standing vertically and striking east. The zone consists of closely spaced veinlets of chrysotile and thinner intervening bands of massive serpentine. Locally more than 50 per cent of the material is asbestos. Fiber up to 1 inch in length is present. Most of it is from 1/16 to ½ inch long. In the north and south walls of the pit there are more widely spaced veinlets of short fiber. A cut in the edge of the serpentine adjacent to the mill shows some short

fiber. Several trenches east of the road in the northern part of the serpentine in SE¼ sec. 17 show small amounts of short fiber.

The Casper Mountain chrysotile varies in color from yellowish-green to amber. Some of it is harsh and brittle. Other material seems to be of good quality. Samples of brittle material from the lens in secs. 16 and 17 show unusual values for refractive index and birefringence. Determinations in oils of a number of fibers from each sample, used to insure different positions of rotation on the long axes of the fibers, are as follows:

Sample No.	n, horiz. hair parallel	n, vert. hair parallel	Birefringence
599	1.465–1.469	1.501–1.505	.032–.040
598	1.482–1.490	1.508–1.514	.018–.032
666	1.494–1.501	1.524–1.533	.023–.039

The samples are all notable for their brittleness, low refractive index and high birefringence. No. 666 is comparable in optical properties with the chrysotile of lowest refractive index and highest birefringence for which Larsen and Berman [9] give data, as follows: $\alpha = 1.493$, $\beta = 1.504$, $\gamma = 1.517$. No. 598 and No. 599 are of still lower refractive index and higher birefringence.

A thin section of No. 599 from the cut near the mill shows massive serpentine with partly altered crystals of olivine, and containing cross-fiber chrysotile veinlets. In a section of normal thickness, the chrysotile shows colors up to second order green. On the basis of this color the birefringence is around .035, a result consistent with that obtained by the immersion method. The olivine, massive serpentine, and chrysotile are cut by quartz veinlets (Fig. 7) some of which parallel the chrysotile veinlets and then turn parallel to the fiber, indicating that the quartz was deposited during or after a period of deformation that pulled the chrysotile away from the walls and fractured it along the fiber. Carbonate, possibly magnesite, is present in veinlets cutting across all minerals except quartz. Compound veinlets with quartz borders and carbonate interiors (Fig. 8) indicate that quartz

[9] Larsen, E. S., and Berman, Harry: Microscopic determination of the nonopaque minerals. U. S. Geol. Surv. Bull. 848: 99, 1934.

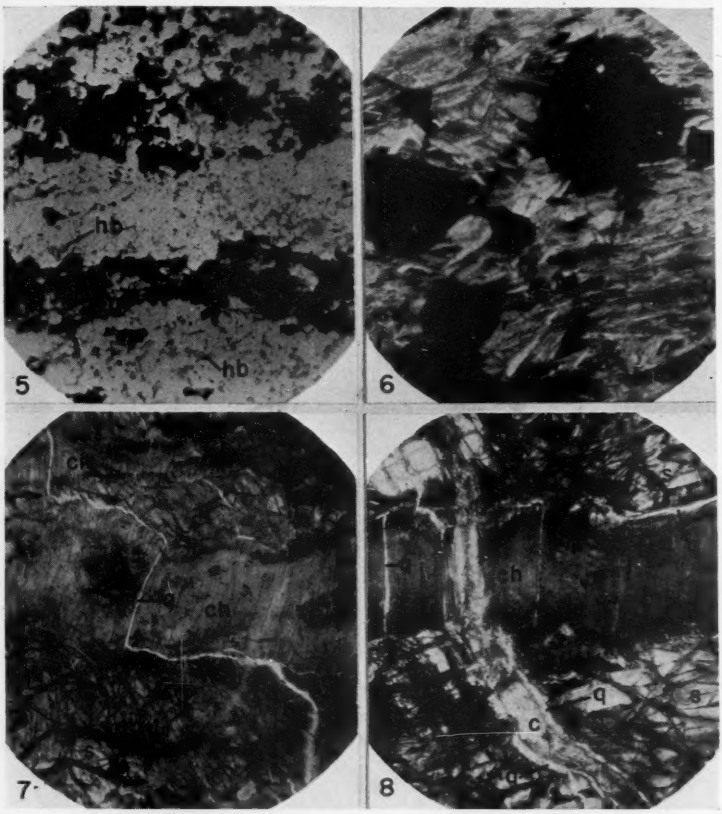


FIG. 5. Schist from the Fire King area showing alternating bands of magnetite (black) and quartz (light) with fine hornblende (hb). Ordinary light. ×75.

FIG. 6. Chromite (black) in chlorite and tremolite matrix (light). Casper Mountain. Crossed nicols. ×75.

FIG. 7. Quartz veinlet (q) cutting serpentine (s) and chrysotile (ch). Casper Mountain. Ordinary light. ×75.

FIG. 8. Compound veinlet of carbonate (c) bordered by quartz (q) cutting serpentine (s) and chrysotile (ch). Crossed nicols. ×75.

began to be deposited first. There was also a period of simultaneous quartz and carbonate deposition.

The serpentine lens from which the brittle chrysotile was collected is bordered on the north by a pegmatite. The most likely source for the quartz and carbonate veinlets is the granite. The writer suggests that there is a relation between introduction of quartz and carbonate and brittleness. It is probable that refractive index and birefringence are not related to brittleness. This subject is separately treated below.

Asbestos deposits in the vicinity of Casper and nearby were worked in 1901.[10] In 1905 Smith wrote,[11]

> Asbestos from the Casper Mountains has been known for some years, and samples recently submitted to asbestos manufacturers have been pronounced of excellent quality. The asbestos is of the chrysotile variety, and the fine silky fiber in the specimens exhibited is of good length. As reported, the chrysotile occurs in a large serpentine dike which has been traced and prospected for several miles.

Some of the later history of development is given in the following quotations:

> With the erection of a mill on Smith Creek and another on Casper Mountain, . . . a production during 1911 was to have been expected if asbestos production was the object in view.[12]
>
> In the Casper region of Wyoming, while the officers of several companies were being prosecuted for their methods of promotion, other companies have extended their prospects and have produced a small quantity of asbestos . . . but the developments are very meager.[13]
>
> The asbestos deposits of Wyoming are largely chrysotile, but they contain only a trace here and there of fair spinning fiber. They have attracted much attention . . . but have not yielded a production. The possibilities of the region are not yet fully known. They should be tested and developed by experienced manufacturers of asbestos who need raw material. There is no doubt that a large quantity of mill fiber of good grade occurs in that part of the country, including the Laramie, Wind River, and Big Horn mountains.[14]
>
> Fred Patee, of Casper, mined from his asbestos property near that city

[10] Pratt, J. H.: U. S. Geol. Surv., Mineral Resources U. S., 1901, p. 891.

[11] Smith, G. O.: U. S. Geol. Surv., Mineral Resources U. S., 1905, p. 1157.

[12] Diller, J. S.: U. S. Geol. Surv., Mineral Resources U. S., 1911, Part II—Nonmetals, p. 998.

[13] Diller, J. S.: U. S. Geol. Surv., Mineral Resources U. S., 1912, Part II—Nonmetals, p. 994.

[14] Diller, J. S.: U. S. Geol. Surv., Mineral Resources U. S., 1916, Part II—Nonmetals, pp. 21–22.

a considerable quantity of serpentine, which was used in making sectional blocks for chimneys.[15]

The writer has not been able to obtain any record of production of asbestos from Casper Mountain in recent years. In 1935 a small tonnage of massive serpentine for concrete aggregate in chimney blocks was quarried from shallow pits a few feet west of the road in the SE ¼ sec. 17.

CHROMITE.

An elongated lenticular mass of chromite-bearing schist, with the foliation parallel to the contacts, crops out in secs. 16, 17, and 20. Boundaries were mapped mainly on the basis of rock fragments in the soil, and consequently are subject to revision. The length as mapped is 2,500 feet and the maximum width 350 feet. The central, northeastern, and other parts of the lens disclose barren schist or a few disseminated grains of chromite up to 1/16 inch across. In the western part of the lens in sec. 20, several trenches cross-cut the schist. One 800 feet west of the section corner shows some thin bands of chromite alternating with schist containing a small amount of disseminated chromite. The banding is somewhat contorted but generally parallels the contacts of the lens. There are also some parallel flattened nodules and pod-shaped masses of rock that appear to be mainly black and dark brown chromite. The pods vary up to two feet in width and a few feet in length. The rock as a whole has the general appearance of a banded gneiss with large flattened augen.

A thin section of disseminated chromite (Fig. 6) shows anhedral chromite in a groundmass of prismatic tremolite and chlorite. Fine-grained chlorite along the tremolite cleavages indicates that the chlorite is younger and was produced, at least in part, by alteration of tremolite. Within the chlorite are areas of fine-grained talc; the age relations of the two are not clear, but the irregular patchy distribution of the talc suggests that it is younger. The mineralogical similarity to other schists in the area that are border phases of the serpentine near contacts with

[15] Sampson, Edward: U. S. Geol. Surv., Mineral Resources U. S., 1920, Part II—Nonmetals, p. 317.

younger granites, provides evidence that the chromite rock was once serpentine. In addition, the succession tremolite—chlorite—talc is well known in the steatization of ultrabasic igneous rocks and serpentine by younger acid intrusives.[16]

The distribution of the chromite, described above, is characteristic of deposits believed to have been formed by early crystallization of chromite from magma.[17] Other features, such as nearby younger granites, and pegmatites that cut ore and schistosity, show that the original ultrabasic rock has been subjected to processes connected with folding and igneous activity later than and unrelated to those of original ore deposition. Considerable attention has been given by Sampson,[18] Ross [19] and Fisher [20] to hydrothermal deposition of chromite. They do not discuss the regional history of the areas around the deposits considered and apparently assume that the hydrothermal solutions originated in the ultrabasic magma. Hess [21] later made a strong distinction between serpentinization produced by solutions originating within ultrabasic magma and steatitization by solutions from later acid intrusions. In the case of the Casper Mountain chromite, there is abundant evidence of steatitization and, judging from the nearby serpentine bodies, there has also been an earlier serpentinization. It is, therefore, possible that further studies of the deposit may provide valuable data on hydrothermal processes in chromite deposits.

The writer collected samples of the chromite ore, but made no attempt at systematic sampling. Nos. 585 and 588 were judged in the field to be representative of the richest material available. No. 587 is schist containing disseminated chromite. Nos. 585A and 588A are concentrates obtained by crushing Nos. 585 and 588

[16] Hess, H. H.: The problem of serpentinization and the origin of certain chrysotile asbestos, talc and soapstone deposits. Econ. Geol., 28: 634–657, 1933.

[17] Diller, J. S.: Recent studies of domestic chromite deposits. A. I. M. E. Trans., 63: 105–149, 1919.

[18] Sampson, Edward: May chromite crystallize late? Econ. Geol., 24: 632–641, 1929.

[19] Ross, C. S.: Is chromite always a magmatic segregation product? Econ. Geol., 24: 641–645, 1929.

[20] Fisher, L. W.: Origin of chromite deposits. Econ. Geol., 24: 691–721, 1929.

[21] *Op. cit.*

and treating the fraction between 115-mesh and 250-mesh with Thoulet solution of specific gravity 3.2. Microscopic examination of the concentrates showed that they contain less than 5 per cent of tremolite and chlorite. In the analyses by H. F. Eppson below, the total iron was calculated as FeO.

Sample No.	588A	588	585A	585	587
Cr_2O_3	46.6%	26.7%	26.6%	13.7%	3.6%
FeO	36.0		63.0		
MgO	4.9				
Al_2O_3	11.0				

The following conclusions can be drawn from the analyses:

1. The Cr_2O_3 content of laboratory concentrate No. 588A is high enough to meet present requirements for the manufacture of ferrochrome.

2. The Cr_2O_3 content of laboratory concentrate No. 585A is too low for this purpose and the high iron content would make it unsuitable for use in chromite brick. The fact that the material is strongly magnetic indicates the presence of a considerable proportion of magnetite.

3. Removal of minerals of specific gravity less than 3.2 from the best appearing hand-picked samples, Nos. 588 and 585, increased the Cr_2O_3 content to an extent showing that silicate gangue minerals constitute 40 to 50 per cent of the rock. Even the best ore would have to be concentrated to meet present market requirements.

4. Some of the schist containing disseminated chromite, as represented by No. 587, is not worth considering for concentration.

Conclusions as to present commercial possibilities of the deposit and its value as a reserve in case chromite should no longer be available from outside the United States can be reached only after much more information is obtained. Quantitative data are needed on, (1) near-surface and depth distribution of materials of high enough Cr_2O_3 content to be suitable for concentration, (2) distribution of magnetite in the deposit, and (3) concentration processes for removal of silicates and possibly also magnetite.

SMITH CREEK ASBESTOS DEPOSIT.

South of Casper Mountain, Paleozoic and Mesozoic beds are involved in a syncline some ten miles wide. The eroded edges of the Deadwood quartzite in the south flank of the syncline form the northwestern boundary of the part of the Laramie Range known locally as the Deer Creek Mountains. The mapped area (Fig. 9) in T. 31 N., R. 78 W., is 27 miles by road from Casper, the nearest rail point.

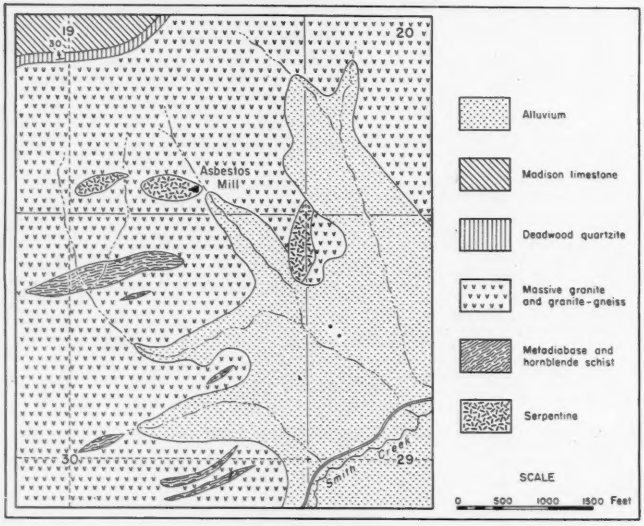


FIG. 9. Geologic map of the vicinity of the Smith Creek asbestos deposit.

The oldest rocks in the area are the serpentines. They are cut by metadiabase dikes of the same period of basic igneous activity disclosed in the southwestern part of the area. The serpentine and basic schists occur as lenses enclosed in granite-gneisses and massive pink granites, and are cut by dikes of granite and pegmatite. It is probable that the lenses are remnants that survived magmatic stoping and granitic injection.

The serpentine masses stand out as low hills above the rolling surface that descends from the base of the Deadwood toward Smith Creek. The serpentine is yellowish-green to black on fresh fracture and weathers light gray. The eastern lens, which is 900 feet long and 350 feet wide, shows no indication of asbestos. The central lens is 650 feet long and 300 feet wide. Near the center is a cut 25 feet wide, 50 feet long, and up to 20 feet deep. The serpentine here is greenish-black in color, and is cut by roughly parallel, vertical veins of cross-fiber chrysotile, which is yellowish-green in color and rather harsh. One band 6 inches wide consists largely of cross fiber. Partings of light green serpentine lie parallel to the walls and reduce the effective fiber length. The longest seen was ¾ inch; most of it is under ½ inch. There is little fiber west of the end of the cut. Apparently the best of the material above the floor level has been mined. A few shallow shafts and trenches farther west show small amounts of short, harsh fiber.

In the side wall of the pit a fracture one inch wide contains a light green, very brittle, columnar and blade-like mineral probably of a variety called metaxite or picrolite. The flat surfaces of the blades lie nearly parallel to the walls in a position similar to that of slip-fiber chrysotile. Because of the general parallelism of the fracture to the system of cross-fiber veins, it is probable that the material was formed at the same time as the cross-fiber and has been sheared, rotated, flattened, and altered, probably during the time of intrusion of the pegmatite dikes in the western end of the serpentine lens. The green material, although fibrous, consists largely of quartz (Fig. 13).

In the western serpentine lens, surface workings expose small amounts of cross-fiber, mostly less than ¼ inch in length in a zone 75 feet wide and 150 feet long. In the immediate vicinity of the fiber, the serpentine is pistachio-green in color and grains of magnetite are visible. Black bands of finely disseminated magnetite, up to ¾ inch wide, form a peculiar interlacing pattern and within each band there are longitudinal veinlets of cross-fiber up to 1/16 inch wide. On several of the dumps in this area

there is short slip-fiber chrysotile and metaxite or picrolite similar to that previously mentioned.

The amount of asbestos mined and milled from the western lens was apparently small, judging from the size of the mill tailing pile, a mound 15 feet high and 30 feet in diameter. As the deposit was worked at the same time as the Casper Mountain asbestos and the two properties were controlled by the same company, the history of the Casper Mountain asbestos development, previously given, covers that of Smith Creek.

DEER CREEK DEPOSITS.

Green Hill Asbestos Deposit.

The deposit is located in sec. 23, T. 31 N., R. 78 W., Natrona County, three miles east of the Smith Creek mill; the Casper-Deer Creek Park road passes just west of the mapped area (Fig. 10).

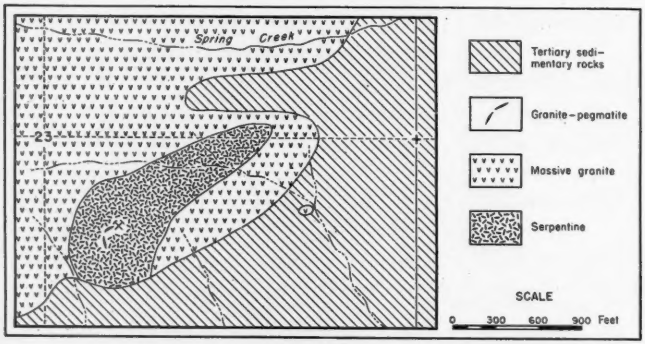


FIG. 10. Geologic map of the vicinity of the Green Hill asbestos deposit.

The deposit is on the rolling upland between Spring Creek, a tributary of Smith Creek, and the West Fork of Deer Creek, which is one-half mile south of the mapped area. A lens of serpentine 1,700 feet long and 500 feet wide forms a hill several hundred feet high and is surrounded by pink granite containing a few xenoliths of hornblende schist. The serpentine is cut by granite-pegmatite dikes.

Northeast of the E¼ cor. sec. 23 a 20-foot diabase dike cuts the granite. It shows a finer-textured border and sends an offshoot into the granite. A thin section shows fresh labradorite and a light yellowish pyroxene. The structure is typically diabasic; there is no evidence of schistosity. This dike is the only evidence seen by the writer near any of the asbestos deposits indicating igneous activity later than the intrusion of the granites. Fine-textured, white, volcanic ash beds of Tertiary age lie unconformably on the granites, but do not extend to the diabase dike. It is probable that the dike is not of Tertiary age, as the Tertiary ashes of this part of Wyoming are andesitic and dacitic in composition, but is instead of pre-Cambrian age and represents the same period of basic activity as the diabase dikes that cut granite near the Pathfinder Dam and the Devil's Gate on the highway between Casper and Rawlins.

Over most of the area of serpentine there is no indication of asbestos. A few feet east of the pegmatite shown on the map, a trench 50 feet long and up to 20 feet deep exposes a veinlet one inch wide, consisting of harsh chrysotile lying at about 45° to the wall. On the dump of a caved shaft a few feet away there are small amounts of harsh slip-fiber chrysotile.

On the same dump there are pieces of brown and black woody material, which show black bands of fibrous magnetite up to half an inch wide, and a few fibers of harsh chrysotile. A thin section shows that the rock consists predominantly of fine-grained quartz and irregular areas of talc. One field in the section shows coarse quartz lying parallel to the fibrous structure. The magnetite occurs concentrated in a few solid opaque areas, and also in finely disseminated form in lines identical in pattern with those of the fibers in a bent and distorted bundle of chrysotile. The writer believes that the woody material is slip-fiber chrysotile that has been silicified, and partly changed to talc and magnetite. Similar material from cross-fiber chrysotile of Casper Mountain has been previously described.[22]

[22] Perry, E. L.: Fibrous magnetite after chrysotile. Am. Jour. Sci., 5th ser., 20: 177–179, 1930.

Koch Asbestos Deposit.

The deposit is located in sec. 15, T. 31 N., R. 77 W., Converse County, on the north side of the West Fork of Deer Creek, near the Casper-Deer Creek Park road.

A lens of serpentine approximately 1,500 feet by 500 feet trending northeast is surrounded by granite. Several smaller lenses 50 to 100 feet wide lie northwest of it. Surface exposures show no asbestos. A 250-foot tunnel that penetrates the large lens discloses a small amount of amphibole asbestos and one vienlet of chrysotile ¼ inch wide. In the first 100 feet of the tunnel, the serpentine is cut by several granite-pegmatite dikes up to two feet wide, bordered by zones of vermiculite up to 8 inches wide.

Deer Creek Canyon Chromite Deposit.

The deposit is located in sec. 11, T. 31 N., R. 77 W., Converse County, in a steep-sided valley draining eastward into Deer Creek, which here flows in a canyon about 1,000 feet deep in the northwest flank of the Laramie Range. The deposit can be reached from the Casper-Deer Creek Park road. It could not be mapped in detail because of deep talus.

Paleozoic beds that cap the uplands are cut by the tributary valley. Along its bottom is a belt of black, strongly sheared rock with a greasy luster, originally an ultrabasic intrusive, that trends N. 75° E. for approximately 1,000 feet to Deer Creek and extends several hundred feet beyond. The width is mostly less than 50 feet. The ultrabasic rock is cut by granite. Near the western end are a number of pits from which chromite has been mined, but at the time of the writer's visit caved walls restricted observations. Spencer [23] reported that there was a layer of fine-grained dense ore 2 to 5 feet thick apparently continuous for 150 feet along the wall of the serpentine. Analyses of ore show 35 to 45 per cent of Cr_2O_3. Carload lots carried 35 per cent of Cr_2O_3. Diller [24] reports that the first ore was mined in 1908 and

[23] Spencer, A. C.: Atlantic gold district and the North Laramie Mountains. U. S. Geol. Surv. Bull. 626: 78, 1916.

[24] Diller, J. S.: Recent studies of domestic chromite deposits. A. I. M. E. Trans., 63: 145, 1920.

that possibly as much as 700 tons had been taken out by 1920. Since then there has been no production.

CANYON CREEK TALC DEPOSIT.

The deposit is located near the crest of the Bighorn Range (Fig. 1) in sec. 25, T. 48 N., R. 86 W., in Washakie County, 48 miles from Buffalo.

In the western part of sec. 25 there are granite-gneisses. In the central and eastern part a folded and schistose succession of greenstones, hornblende schists and olivine metadiabases strikes N. 15° E. and passes beneath the Deadwood quartzite in the next section to the south. Locally, there are very small amounts of brittle amphibole asbestos and talc in the schists. No chrysotile was seen. In the summer of 1934 the Wyoming Asbestos Mining Co. was employing 10 to 12 men in prospecting in the SE ¼ sec. 24. Prospect pits and a 25-foot shaft show only talc schist and fibrous talc.

CAUSE OF BRITTLENESS AND HARSHNESS IN CHRYSOTILE.

Soboleff and Tatarinoff state in their summary of conclusions on the cause of brittleness and harshness in asbestos:[25]

1. On the basis of the field investigations of the Rhodesian and Iltchirsk occurrences of chrysotile-asbestos it may be conclusively stated that brittle asbestos is a transition stage not between serpentine and normal asbestos, but between the latter and talc.
2. In most cases normal asbestos contains an excess of water.
3. Brittle chrysotile-asbestos (*a*) is characterized by an excess of SiO_2 and occasionally MgO; (*b*) it may be regarded as a product of metamorphism of normal chysotile-asbestos; (*c*) the explanation of the brittleness by the presence of CaO in the chemical composition of asbestos, *i.e.* by the isomorphous replacement of the MgO, is inconclusive.

With respect to the work of Keep[26] they say:[27]

Keep seems to have shown rather conclusively from his field investigations that brittle asbestos is but a transition stage between normal asbestos

[25] Soboleff, N. D., and Tatarinoff, M. V.: The cause of brittleness in chrysotile asbestos. ECON. GEOL., 28: 175–176, 1933.

[26] Keep, F. E.: The geology of the Shabani mineral belt, Belingiwe District. Geol. Surv. S. Rhodesia, Bull. 12, 1929.

[27] *Op. cit.*, p. 172.

and talc. In the latter there are veins consisting of pseudomorphs of talc after asbestos. Keep has made numerous chemical analyses of both types of chrysotile-asbestos, and has attempted to interpret them. However, his method of calculating these analyses into the mineralogical composition has not given positive results, although he remarks [28] that "with a decrease of the serpentine constituent and an increase of talc, corresponding to a decrease in silica, the fibers become brittle."

In connection with harshness in chrysotile occurring in limestones Bateman says: [29]

> The extremely harsh material cannot be utilized; the slightly harsh grade can be spun but yields a splintery yarn; the intermediate material, which constitutes the greatest amount of the harsh asbestos, can be used for spinning fiber only after a preliminary acid wash.

Of the Arizona chrysotile deposits occurring in limestones Diller says: [30]

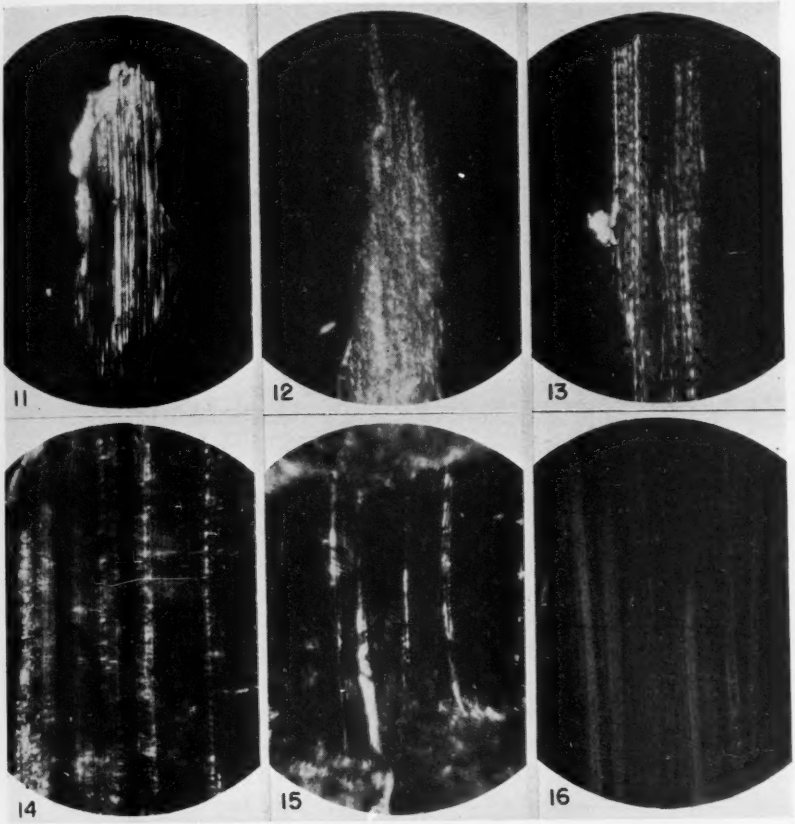
> A. B. Shutts, general manager of the American Ores & Asbestos Co.'s mine, has given much attention to harsh and soft fiber; both are said to occur in the same vein, and he reports them as grading into each other. He called the writer's attention to veins of fibrous calcite in which the asbestos appears to have been so completely replaced by fibrous calcite that the calcite is pseudomorphous and preserves the fibrous structure of the chrysotile. Mr. Sampson suggests that the fibrous calcite may be a parallel growth instead of a replacement of chrysotile. The degree of harshness varies and appears to be proportionate to the degree of replacement of the asbestos by the calcite. These facts seem to furnish strong and convincing evidence that calcite causes the harshness of the fiber.

The writer believes that the apparent inconsistencies in the quotations above are the result of assuming that brittle and harsh chrysotile in the serpentine type of deposit and in the limestone type are formed by identical processes and that undue emphasis has been given to conclusions based on chemical analyses of materials which had not been subjected to detailed microscopic examination at high magnifications. Harshness and brittleness of chrysotile in the deposits examined by the writer are explicable by silicification of chrysotile in varying degrees and with or without chemical reaction between silica and chrysotile, by solutions from the granites found in the immediate vicinity. This process explains, as set forth below, some of the apparent inconsistencies

[28] *Op. cit.*, p. 111.

[29] Bateman, A. M.: An Arizona asbestos deposit. ECON. GEOL., 18: 669, 1923.

[30] Diller, J. S.: U. S. Geol. Surv., Mineral Resources U. S., 1919, Part II—Nonmetals, p. 303.



FIGS. 11–16. Photomicrographs with crossed nicols and at extinction position. FIG. 11. Tiger-eye, South Africa. ×70; FIG. 12. Brittle chrysotile, Brown Bear. ×70; FIG. 13. Picrolite or metaxite, Smith Creek. ×70; FIG. 14. Harsh chrysotile, Brown Bear. ×210; FIG. 15. Harsh chrysotile, Casper Mountain. ×210; FIG. 16. Spinning-fiber chrysotile, Quebec. ×210.

encountered in interpretations of chemical analyses of samples from the serpentine type of deposit and also strongly suggests that brittleness and harshness in chrysotile from the limestone type of deposit is the result of varying degrees of replacement of chrysotile by calcite.

Figures 11 to 16, all of which were taken with crossed nicols at extinction position, are arranged in order from almost pure quartz to the finest grade of spinning fiber. The hand specimen of yellowish tiger-eye from South Africa, from which Fig. 11 was prepared, has the usual extreme brittleness of quartz and a subconchoidal fracture. The material has such poor fibrous structure that many of the fragments obtained by crushing are elongated across the fiber length. The photomicrograph shows that the quartz is coarse, but fails to give an adequate picture of the amount of quartz, as the red interference colors registered as black in the print, because of the use of orthochromatic film.

One of the slip-fiber veins of the Brown Bear deposit has been invaded by a granite-pegmatite and much of the fiber has been replaced by quartz. The fragment in Fig. 12 is from approximately one inch out from the wall of the original ultrabasic rock. Between one end of the fiber, which is approximately ½ inch long, and the wall is a quartz veinlet; at the other end is a dikelet of quartz and orthoclase. The green fibrous material is so tough and brittle that considerable force is needed to drive a knife blade into the specimen holding the flat surface of the blade parallel to fiber length. The material flies into small bits when struck with a hammer. The photomicrograph shows the mosaic of introduced quartz and gives a suggestion of the "ladder" structure shown prominently in Fig. 13.

The fragment in Fig. 13 is from near the middle of the central serpentine lens at Smith Creek. The long axis was originally nearly parallel to the walls of the enclosing massive serpentine. The hand specimens are blades and columns several inches long and up to an inch thick. When one attempts to bend a blade it breaks with a snap. The mineral is a variety to which the name picrolite or metaxite has been applied. The photomicrograph

shows veinlets or rods of quartz parallel to fiber length and, between them, fairly evenly spaced elliptical spots of quartz. The structure suggests a number of parallel ladders.

The fiber in Fig. 14 is from the same hand specimen as the fregment in Fig. 12, but lies in contact with the wall rock at one end and is separated from the material of Fig. 12 by a quartz veinlet about 1/10 inch wide. The fiber is very harsh. After working it in the fingers splinters remain in the skin. The quartz mosaic shown is finer than that in the preceding figures, as the magnification is greater. The structural arrangement of quartz is similar to that in Fig. 13. In addition, some bands show no quartz mosaic even when turned slightly away from extinction position, and quartz also cuts across normal to fiber length.

Fig. 15 is a field of a thin section from hand specimen No. 599, greenish-yellow serpentine containing interlacing veinlets of harsh chrysotile up to ⅛ inch in length. The chrysotile has a very low refractive index and high birefringence, properties which are probably not genetically related to harshness. Other fields in the same thin section are shown in Figs. 7 and 8. As explained in connection with the description of the Casper Mountain asbestos, the thin section shows the history: (1) Fracturing of serpentine and chrysotile. (2) Deposition of quartz in veinlets, which cut across massive serpentine, extend up to the boundary of a chrysotile veinlet, spread along the contact between massive serpentine and chrysotile, and then cut across the chrysotile parallel to fiber length (Fig. 7). (3) Deposition of carbonate material (Fig. 8). The specimen was collected in the cut near the Casper Mountain mill. The serpentine is here bordered on the north by a granite-pegmatite, an obvious source for the quartz. The photomicrograph (Fig. 15) shows a number of streaks of quartz lying parallel to fiber length. Some are undoubtedly tabular veinlets. Others may be rod-shaped. The narrowest prominent quartz streak near the center of the field is 6 to 7 microns wide. In addition to obvious quartz streaks there is a strong suggestion of "ladder" structure. The dark bands along the borders of chrysotile veinlets (Figs. 7 and 8) indicate that silicification pro-

ceeded inward parallel to fiber length from the quartz separating the fiber ends from massive serpentine.

Fig. 16, given for comparison, is an excellent grade of spinning fiber from Quebec. The failure to show complete extinction is the result of a slight crossing of the fibers produced during cutting the bundle with scissors. Soft flexible fiber from Wyoming deposits shows the same lack of visible " ladder " structure at the same magnification.

The microscopic evidence is entirely in accord with the findings of Soboleff and Tatarinoff and with those of Keep. Introduced quartz in brittle chrysotile would appear in a chemical analysis as an excess of SiO_2 over the amount necessary for the composition of chrysotile. In the preparation of material for chemical analysis, the presence of a few very fine carbonate veinlets is likely to be overlooked. If the carbonate material is magnesite the analysis would show an excess of MgO. If the carbonate material contains calcite or dolomite or both the analysis would show CaO, which, on the assumption that the material analyzed was pure, would lead to the conclusion that CaO occurs as an isomorphous replacement of MgO. Low water and high SiO_2 content would necessarily appear in a chemical analysis of impure material in which chrysotile has been partially replaced by anhydrous silica. Keep's observation that brittle chrysotile is but a transition stage between normal chrysotile ($2H_2O \cdot 3MgO \cdot 2SiO_2$) and talc ($H_2O \cdot 3MgO \cdot 4SiO_2$) implies that the conversion process involves both loss of water and addition of SiO_2. The difficulties encountered in calculating Keep's chemical analyses into mineralogical compositions expressed in terms of chrysotile and talc strongly suggest to the writer that the difficulties are not in the method of calculation, but that the analyzed material contained free quartz or magnesite, which Hess [31] has shown is one of the end stage products of the steatitization of serpentine masses by granites.

The observations of Bateman on the effect of an acid wash on

[31] Hess, H. H.: The problem of serpentinization and the origin of certain chrysotile asbestos, talc and soapstone deposits. ECON. GEOL., 28: 634–657, 1933.

slightly harsh chrysotile from the limestone type of deposit and Diller's description of the continuous transition from fibrous calcite through harsh and brittle varieties to the best grade of chrysotile suggest that, in this type of deposit, brittleness and harshness are the result of the presence of replacing calcite arranged in a pattern similar to that of the quartz in brittle chrysotile from the serpentine type of deposit.

UNIVERSITY OF WYOMING,
LARAMIE, WYOMING,
June 1, 1939.

DISCUSSION AND COMMUNICATIONS

ALTERATION OF ILMENITE.

Sir: In his paper on the Iron Ores of Wichita Mountains, Oklahoma, on page 279 of the current volume of this JOURNAL, Mr. C. A. Merritt makes a statement, which is commonly met with in the literature, namely that ilmenite has been altered by surface weathering to leucoxene (titanite in small crystals), and to limonite. The occurrence of titanite (sphene) in alpine fissures has been thought to indicate temperatures of formation between 180° and 250° C., or at any rate not below 150° C. Can proof be advanced for the iron ore of the Wichita Mountains to show that both minerals result from surface weathering of titaniferous magnetite below 100° C., and not to hydrothermal action?

JOH. G. KOENIGSBERGER.

FREIBURG, I. B.,
GERMANY,
July 7, 1939.

REVIEWS*

Geology and Allied Sciences. Thesaurus and Coordination of English and German Specific and General Terms. By WALTHER HUEBNER. Part I, German-English. Pp. 405. Veritas Press, New York, 1939. Price, $7.50.

This critical dictionary is the culmination of 15 years of work and is a much needed thesaurus of modern German-English geologic terms. There are given corresponding English words or phrases for more than 25,000 German specific and general terms, many with definitions. "Abbreviations used in international geologic literature are included as well as those of names of authors. Commercial terms are omitted; of mining terms only the common ones will be found." Related terms are grouped under one key word thus facilitating the finding of them.

In some instances there seems to be unnecessary vocabularly padding by bracketing two such identical words as *planetesimals* and *planitesimals* but it is far preferable to have a few superfluous, rather than a dearth of, terms in a scientific dictionary. There are some errors of translation and definition as would be expected when one man attempts to cover so broad a field but the whole is a comprehensive work, the best of its kind, and a book that every student of geology dealing with German literature will wish to have despite the high price.

W. S. BAYLEY.

Strategic Mineral Supplies. By G. A. ROUSH. Pp. 485; Charts, 40; Tables, 82. McGraw-Hill Book Co., New York, 1939. Price, $5.00.

This book made a more timely appearance than its author and publishers could have hoped, for hardly was war declared when it came off the press. It is based upon a series of articles by the author that appeared in "The Military Engineer," and upon his lectures before the Army Industrial College. In addition, the author exudes his store of statistical data, available to him as Editor of "Mineral Industry."

The subject revolves around strategic minerals from the standpoint of the United States, 40 per cent of whose mineral imports are strategic. Chapters 1 and 2 deal with strategic and critical minerals and shortages and maintenance of supply. Chapters follow on manganese, nickel, chromium, tungsten, tin, aluminum, antimony, mercury, platinum, mica,

* Books noted under *Reviews* and *Books Received* may be ordered through the Economic Geology Bookshop, W. S. Bayley, Urbana, Ill., but orders for official reports and single copies of Journals should be sent directly to their publishers.

iodine, nitrogen, domestic self sufficiency, supplies in foreign countries and commercial vs. political interests. Considered under each mineral are requirements, uses, substitutes, ores, reserves, world output and supply, U. S. output and supply, utilization, prices and tariffs. Statistics are complete up to 1937.

The material is well organized for ready reference and the statistical matter is in handier form than in "Mineral Industry" and "Minerals Yearbook." It is an excellent reference book for geologists, metallurgists, economists and all users of strategic minerals. In view of the military, government and public interest in strategic minerals it is extremely timely.

ALAN BATEMAN.

Geomorphology—An Introduction to the Study of Landscapes. By A. K. LOBECK. Pp. 731; Illust. McGraw-Hill Book Co., New York, 1939. Price, $4.50.

This book immediately catches the eye because of its numerous striking half-tones that completely fill the page, many of them splendid aerial views; to leaf it through is a fascinating picture study. The excellent photographs (lacking figure numbers) almost submerge the fine bold line-drawings such as one has learned to expect from the author. Subsequently the reader may notice that the book also contains text matter; if he is statistically minded he can figure that out of the 731 pages, 384 full pages are illustrations and 68 are devoted to questions, references and index, leaving only 269 pages, or 37 per cent, for text matter. Thus, statistically, the book is largely geomorphology by pictures and references, but snuggled among them are compact meaty discussions. Incidentally, there may be some question as to how much geomorphology is included since a goodly part of the subject matter appears to be a combination of standard physical geology and old fashioned physical geography, leaving very little for real geomorphology. Practically all of the subject matter is to be found, without the beautiful illustrations, in standard textbooks of physical geology, but greater emphasis is placed on land forms for, as the title states, the book is an introduction to the study of landscapes.

After an introductory chapter, the subjects treated are Rocks and Rock Structures; Weathering; Underground Water; Streams; Alpine and Continental Glaciation; Waves; Wind; Organisms; Coastal Plains; Plains and Plateaus; Dome, Block, Folded and Complex Mountains; Volcanoes; and Meteor Craters. These chapter titles make us continue to wonder why the book is called *Geomorphology*, but it is a grand display that every student of geology should see and it is an excellent modern introduction to landscapes.

ALAN BATEMAN.

A Source Book in Geology. By KIRTLEY F. MATHER AND S. L. MASON. Pp. 702; Figs. 42. McGraw-Hill Co., New York, 1939. Price, $5.00.

This is one of a series of Source Books in the History of Science under the editorship of G. D. Walcott. It provides representative excerpts from original writings, somewhat along the same lines used in Geology from Original Sources by Agar, Flint and Longwell. Excerpts are arranged chronologically and a guide has been provided to enable one to turn to various subjects of geology. Excerpts cease at 1900 and the writings of living geologists have not been included. The carefully chosen excerpts give a comprehensive view of the development of geological sciences; many are from obscure writings or translated from foreign languages. The book provides an excellent background for students of geology.

Internal Constitution of the Earth. Physics of the Earth, VII. Edited by BENO GUTENBERG. Pp. 413; figs. 25. McGraw-Hill Book Co., New York, 1939. Price, $5.00.

This is another excellent monograph of the "Committee on the Interior of the Earth" of the National Research Council, with nine outstanding contributors. Although there is some overlap and a few disagreements enter, this broad field is covered exhaustively. The individual contributions are: Introduction, B. Gutenberg; Origin of the Solar System, Harold Jeffreys; Facts and Inferences from Field Geology, R. A. Daly; Elastic Properties of Earth's Crust, L. H. Adams; The Crust and its Relation to the Interior, H. S. Washington, revised by L. H. Adams; Observed Temperatures, C. E. Van Ostrand; Cooling and Interior Temperature, Forces in the Earth's Crust, Hypotheses of Development, Elastic Constants, Viscosity Strength and Internal Friction, and Summary, all by B. Gutenberg; Evidence of the Interior from Seismic Sources, J. B. Macelwane; Evidence from Deep-focus Earthquakes, and Structure of the Crust-continents and Oceans, B. Gutenberg and C. F. Richter; Density, Gravity, Pressure and Ellipticity in the Interior, W. D. Lambert.

This is an imposing array of subjects that cover the latest knowledge in this interesting field.

BOOKS RECEIVED.

DAVID GALLAGHER.

Theoria do Protogneis. A. R. LAMEGO. Pp. 67; figs. 20; pls. 28; geol. map. Serviço Geol. E. Min., Bull. 86, Rio de Janeiro, 1938. *Revolutionary concept that the whole Archean series of rocks in the Rio de Janeiro district, including the dolomites, were derived from a single type of fundamental orthogneiss—protogneiss—through the metamorphic action of a granitic magma. The protogneiss represents the primitive shell of the earth solidified from a molten condition. The*

Brazilian Archean is the only true Archean known at present and is named the Brazilian Era. This is the antithesis of the modern concept that many types of Archean gneisses are derived from the action of a granitic magma on sedimentary rocks.

Preliminary Reports of the Geological and Mineralogical Service of Brazil, 1937. No. 8: O Clima do Brasil; O Petroleo do Lobato, Bahia, pp. 16. **No. 9: Prospecção Geophysica no Estado do Paraná; Fosseis Pleiocenios do Rio Jurvá, Estado do Amazonas; Politica do Ferro; Notas Geological Tomadas em uma Viagem na Estrada de Ferro Sao Paulo a Minas,** pp. 16. **No. 13: Genese dos Combustiveis; Considerações Sobre o Merito do Bull. 5,** pp. 16. **No. 14: Minerios de Ferro do Brasil; Crocodilianos Fosseis do Brasil; Madeiras Fosseis Petrificadas,** pp. 15. **No. 16: A. Gypsita da Boa Vista,** pp. 16; Rio de Janeiro, 1937.

Index of Research Projects. Vol. I. H. R. HOSEA, ed. Pp. 291. W. P. A., Washington, 1938. *Digest and index of 2000 research projects in natural and social sciences.*

Legislation Minière, Carrières et Toubieres. Mines, Carrières, Grandes Entreprises. L. DE MALSONCELLE. Pp. 196. Paris, 1938. Price, 35 frs. *Definition of terms and summary of laws governing mining and quarrying in France; brief account of the State authorities controlling operations.*

Lexicon of Geologic Names of the United States. Part 1, A–L, Part 2, M–Z. Compiled by M. GRACE WILMARTH. Pp. 2396. U. S. Geol. Surv. Bull. 896, 1938. Price, $2.50. *A monumental work that will become a valuable reference guide to American geologists.*

Prospeccion y Explotacion en Pequeña Escala de los Lavaderos Auriferos. WILLIAM F. BOERICKE. Traducida por A.D. Semanate. Pp. 229. El Banco Central del Ecuador, 1938. *A translation of Boericke's "Prospecting and operating small gold placers," with additional appendices of prospecting, legal matters and tables of weights and measures.*

The Tetons—Interpretations of a Mountain Landscape. FRITIOF FRYXELL. Pp. 77; figs. 24; map. Univ. of Cal. Press, Berkeley, 1938. Price, $1.50. *Interesting geological and landscape description of the Grand Teton National Park, Wyoming; well written and illustrated.*

Canadian Mines Handbook for 1939. Pp. 416. Northern Miner Press, Toronto, 1939. Price, $1.00. *Reviews of 5526 mining companies, divided into active, inactive and extinct companies; 1404 active mining organizations and 155 producing gold mines; officials, financial, property, development, reserves, production.*

Birth of the Oil Industry. P. H. GIDDENS. Pp. 216. Macmillan and Co., New York, 1938. Price, $3.00. *A carefully documented and dramatic account of the history of oil development in America up to 1870.*

Grade of Ore. A. V. CORRY AND O. E. KIESSLING. Pp. 114; charts, 24. Nat. Research Project and U. S. Bur. Mines. W.P.A., Washington, 1938. *Statistical and interpretative study of declining yield in gold, silver, copper, lead and zinc ores; technologic changes in various districts; very informative.*

Die alten Eisenindustrien des Fricktales, bei Erlinsbach und in venachbarten Gebieten des östlichen Juras im Licht der Flurnamen. ALF. AMSLER. Pp. 56; map. Beit. z. Geol. der Schweiz. Geol. Ser. No. 6. Aarau, 1938. *Historical, descriptive.*

Geotechnische Karte der Schweiz, Sheet No. 4, Bellinzona-St. Moritz. P. NIGGLI AND F. DE QUERVAIN. Scale 1:200,000; size 24 × 40; colored; with text, 124 pp. Geotech. Komm. der Schweiz. Bern, 1938. *Fourth map of series.*

Preliminary Report on Some Refractory Clays of W. Oregon. H WILSON AND R. C. TREASHER. Pp. 93; figs. 38; mimeographed. Dept Geol. and Nat. Res. and U. S. Bur. Mines. Bull. No. 6. Portland 1938. Price, 45 cts. *Geology; descriptions by districts; tests.*

Annales du Service des Mines. Com. Spec. du Katanga. Vol. 8, 1937. Pp. 65. Brussels, 1938. *Contains following papers: Trieuite et les Minerâux associés by L. de Leenheer; Cherts du Kundelungu S. by P. Grosemans and A. Jamotte; Schist amygdaloïde à dipyre du Katanga M. by F. Corin; Minerais de manganèse du Katanga by L. de Leenheer.*

Canadian Mineral Industry in 1937. The Staff. Pp. 99. No. 791. Bur. of Mines, Ottawa, 1938. *Annual review of metals, industrial minerals, and fuels.*

Probleum in New Zealand. J. HENDERSON. Pp. 26. Bull. 60, Indust. Research. Wellington, 1937. *Small stones; favorable source rocks and structure.*

Analyses of Pennsylvania Bituminous Coals. GEORGE H. ASHLEY. Pp. 503; figs. 5. U. S. Bur. Mines Techn. Pap. 590, Washington, 1939. Price, 50 cts.

Annual Report, 1938. Geol. Surv. Uganda. Pp. 40; map. Entebbe, 1939. Price, 2/–.

Geological Maps. Canada Dept. Mines and Resources, Geol. Surv. 411A and 412A Hearst Kapuskasing Area, Ontario; 454A Amulet Area, 455A Waite Area, 456A Newbec Area, 457A Dufault Area, Quebec. Ottawa, 1939.

Carbonizing Properties and Petrographic Composition of Washed and Unwashed Lower and Upper Kittanning Bed Coals from Mines 72 and 73, Johnstown, Cambria Co., Pennsylvania. A. C. FIELDNER ET AL. Pp. 83; figs. 53. U. S. Bur. Mines Techn. Pap. 595, Washington, 1939. Price, 10 cts.

Methods of Analyzing Coal and Coke. F. M. STANTON, A. C. FIELDNER AND W. A. SELVIG. Pp. 59; figs. 17. U. S. Bur. Mines Techn. Pap. 8, Washington, 1939. Price, 15 cts. *Revision of 1929 edition.*

Geology and Oil and Gas Resources of Logan, Gove and Trego Counties, Kansas. K. K. LANDES AND R. P. KEROHER. Pp. 45; figs. 8; pls. 4. Kansas Geol. Surv. Min. Resources Circ. 11, Lawrence, 1939. *Report to aid future exploration for oil and gas in western and northwestern Kansas.*

La Industria Minera en el Perú, 1937. JORGE HOHAGEN. Pp. 330. Cuerpo de Ingenieros de Minas del Peru, Bol. 122, Lima, 1938.

SCIENTIFIC NOTES AND NEWS

EDWIN B. ECKEL, who has been with the U. S. Geological Survey, has been appointed to the Purdue University department of metallurgy.

E. L. BRUCE has completed examination of the Goudreau Area north of Lake Superior and returned to Kingston, Ontario.

J. D. FORRESTER has been made head of the department of geology at the University of Idaho.

The MONTANA SCHOOL OF MINES and the state BUREAU OF MINES are sponsoring a W.P.A. mineral survey to be made of the manganese, tungsten and chrome resources of the state.

GEOFFREY GILBERT has gone to Trail, B. C. as geologist for Consolidated Mining and Smelting Co.

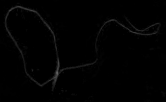
ROGER H. SHERMAN, formerly assistant chief geologist, is now head of the exploration department of the Standard Oil Co. of Venezuela at Caracas.

The SOCIETY OF ECONOMIC GEOLOGISTS will meet jointly with the Geological Society of America, the Mineralogical Society, and the Paleontological Society, Dec. 28–30, 1939, at the Univ. of Minnesota, Minneapolis, Minn. The program has not yet been closed and papers dealing with economic geology are earnestly solicited. Titles together with abstracts not to exceed 250 words, an estimate of time required for presentation and whether a lantern is necessary, should be in the hands of the Secretary, W. D. Johnston, Jr., or of the Chairman of the Program Committee, C. H. Behre, Jr., Dept. of Geology, Northwestern University, Evanston, Ill., not later than Nov. 15.

At the Society's California meeting with the G. S. A. in August, 40 members and guests went to Grass Valley, Allegheny, and the Comstock Lode under the leadership of C. D. Hulin, and were conducted underground by the mine staffs. Two evening sessions at Grass Valley were devoted to discussions of the districts visited.

The A. I. M. E., PETROLEUM DIVISION, held fall meetings at Galveston, October 5–7, and at Los Angeles, Oct. 19–20, at which 22, and 24 papers were presented in the technical sessions.

The INDUSTRIAL MINERALS DIVISION of the A. I. M. E. will hold a fall meeting at Tuscaloosa, November 2–4.

DONALD C. BARTON, consulting research geologist and geophysicist for Humble Oil and Refining Co., died July 9, in Houston, Texas.

W. A. TARR, professor of economic geology, University of Missouri, died on July 28.